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THE NUMBER AND DISTRIBUTION OF THE STARS IN THE VICINITY OF THE PLEIADES.

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FOR POPULAR ASTRONOMY.

When one looks with the naked eye at the Pleiades group of stars on a very clear night he sees six stars easily; by looking more closely he may see seven and possibly eight or nine stars in the cluster. A few persons, under exceptional circumstances, have claimed to be able to detect as many as fourteen stars in the group. The length of the group of bright stars is almost exactly 1°, east and west, and the width is about 40′. Around it within a radius of five degrees there is but one star as bright as the fifth magnitude and only ten of the sixth magnitude, which last magnitude is just barely visible to the naked eye on a good clear night. The six bright stars thus appear to be associated together and to be separated from others of the same degree of brightness.

When a telescope of low power or even a pair of opera glasses is turned upon this group an amazing number of stars is revealed. The group becomes a veritable star cluster, the field of view being strewn with glittering points of all degrees of brightness, about 70 being as bright as the ninth magnitude. In 1664 Robert Hooke with a telescope of scarcely two inches aperture counted seventy-eight Pleiades and in 1767 Michell conjectured that there might be a thousand of them. This conjecture has been abundantly verified in recent years by the aid of that wonderfully powerful adjunct of astronomy the sensitive photographic plate.

The images of stars being fixed upon a plate of glass it becomes a comparatively easy task for the astronomer to make an accurate count of all that fall within a definite area. In 1876 M. Wolf at the Paris Observatory, catalogued 625 stars down to the fourteenth magnitude within an area $135' \times 90'$ having Alcyone as its center. The M M. Henry at Paris in 1885, counted 1421 in a smaller area and in 1887, by exposures of four hours duration, brought the number up to 2326. Again in 1897 Pro-

fessor Bailey of Harvard College Observatory, counting the stars upon a negative taken with the 24-inch Bruce telescope with an exposure of six hours, found 3972 stars within an area 2° square having Alcyone at its center.

The writer at odd moments during this winter has been counting the stars on several of the long exposure photographs of the Pleiades taken at Goodsell Observatory. Upon one with an ex-

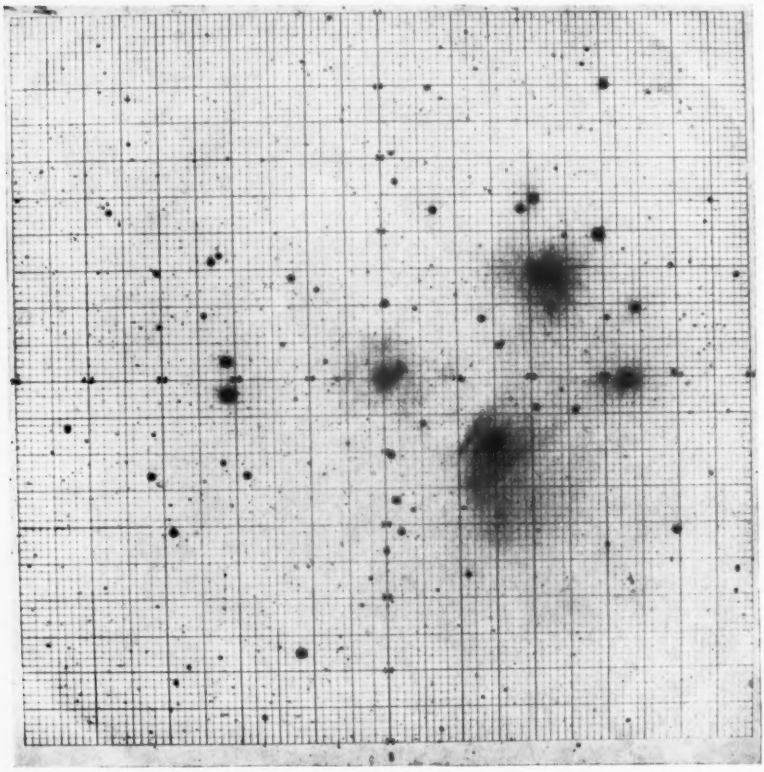


FIG. 1. Showing a Negative of the Pleiades laid upon a reticle for the purpose of counting.

posure of seven hours with the eight-inch telescope, within an area less than 110′ square the number comes out 3021; and upon another with an exposure of sixteen hours the number in the same area is 4621. In that little area less than 2° square there are thus two thirds as many stars as are visible to the naked eye over the entire celestial sphere.

That all of these stars belong to the Pleiades group is not at all probable. The great majority of them probably lie at immense distances beyond the group and simply appear in it by projection. It has been found, however, by very careful measurements made during the last seventy years at the Königsburg and Yale Observatories that of the sixty-nine brighter stars, including those down to the ninth magnitude, only eight show any certain movement with reference to Alcyone. Since Alcyone has a proper motion or drift of 6″ per century, this means that all of the brighter stars except the eight mentioned are drifting with Alcyone and so form a true cluster, at approximately the same distance from the Earth. Six of the eight stars which show relative drift are moving in the opposite direction to the movement of Alcyone and at nearly the same rate so that their motion is only apparent. They are really stationary while Alcyone and the rest of the cluster are moving past them. There are no measures of the fainter stars old enough yet to give us any clue to their movements. We shall have to wait a good part of a century yet before these extremely minute displacements will become large enough to reveal themselves with any degree of certainty.

The cut Figure 1 shows a negative of the Pleiades laid film down upon a ruled glass plate for the purpose of counting the stars. The scale is 1′.1 to the smallest squares and 5′.5 for the larger squares, so that the area of a larger square, for each of which the count is given, is 30′.25. The tube of the telescope causes the exposed area of the plate to be circular so that there are several vacant squares at each corner. For the purpose of counting the ruled plate is placed in a frame which may be moved in one direction while a bar carrying an eyepiece of moderate magnifying power may be moved in the transverse direction over the plate. It is thus possible to bring the squares in succession under the eye and to count the star images without duplication.

The reader familiar with the Pleiades will at once recognize the six bright stars from their having the largest black images. At the center is Alcyone; to the left below the middle line is Atlas; above the line Pleione; to the right on the middle line, Electra; below, surrounded by a great cloud of nebulosity, Merope; above, in a smaller but denser cloud, Maia. Near Maia to the west and north are four less bright stars which are sometimes detected with the naked eye: Celoena, Taygeta, Asterope[1] and Asterope[2].

This negative was given an exposure of seven hours on the nights of November 7 and 8, 1899, in the eight-inch Clark tele

scope, which for photographic work is provided with a third lens placed in front of the visual objective. When in perfect adjustment it gives fine images over almost the entire field. The nights were very clear and the atmosphere exceedingly transparent.

The results of the count are shown in detail in the cut Figure 2, in which the squares correspond to those on the plate and the

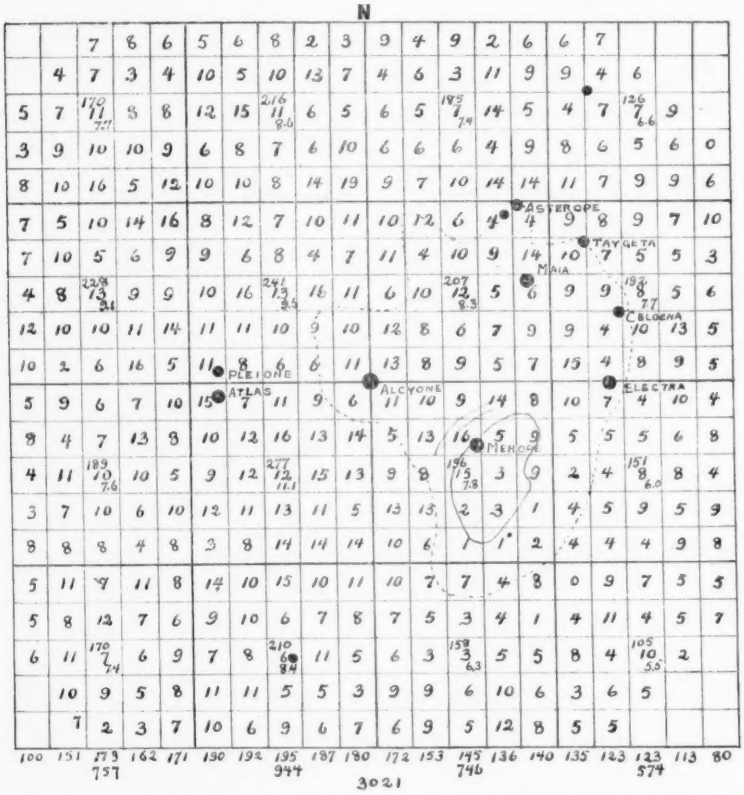


FIG. 2. Count of the Stars upon a Pleiades Negative of 7 hours exposure, taken with the 8-inch photographic telescope of Goodsell Observatory. The small squares are 5′.5 by 5′.5.

figure in the center of each square gives the number of star images found in that square. In the count many faint stains were discarded as too uncertain to be regarded as real star images. Minute dust spots and other faults in the film were in most cases easily recognized under the magnifying power of the eyepiece used. The positions of the bright stars of the group and the

outline of the brightest nebulous areas are indicated in the cut for convenience of reference.

It is evident at a glance that the faint stars are not uniformly distributed in and around the group. They are more thickly strewn over the east half of the plate than over the west half. This may be explained by the fact that the Pleiades group is only 20° from the bright part of the Milky Way and has thus for its background the fainter extension of the Galaxy which fades off gradually toward the west. There appears, however, to be a real *lacuna* among the stars in and south of the Merope Nebula. This is not because of the photographic effect of the nebula, for a slight fogging of the sensitive plate such as the nebula produces should have the effect of enhancing, assisting in bringing out, feeble star images.

In order to study the average distribution in the different parts of the plate I have divided it into sixteen blocks of twenty-five squares each. The totals in each block are given in the upper part of the center square of each block and the averages in the lower part. The totals in the corner blocks of course are small but the averages correspond with the others. The greatest condensation appears to be in the two blocks east of the center of the plate, where the averages are 9.6 and 11.1 stars per square. In the two blocks west of Alcyone the averages are 8.3 and 7.8 respectively. The average for the four blocks around the center is 9.2, while that for the twelve blocks outside of these is 7.4 or, omitting the four corner blocks, 7.6. The average for the entire 382 squares is 7.9. It thus appears that the stars are thicker within the Pleiades group than they are around it. This is contrary to the conclusion arrived at by Professor Bailey in the count, already referred to, at Harvard College Observatory. Professor Pickering in speaking of this count says:

"It therefore appears that the total number of stars in the region of the Pleiades is *actually less* than that in adjacent portions of the sky, of equal area, and it is much less than the corresponding number in many parts of the Milky Way."

Professor Bailey counted the stars in squares 10′ on a side so that the area of each was one hundred square minutes of arc. The forty-two squares including the bright stars of the group yielded an average of twenty-four per square, while for the whole area covered the average was twenty-eight stars per square. It is rather remarkable that my averages when reduced to the same scale become thirty and twenty-six respectively, just reversing the relation of the numbers. It is remarkable also that a

photograph of seven hours exposure with an eight-inch telescope should yield so nearly the same number of faint stars, as one taken with a twenty-four inch telescope and a six hour exposure.

The discrepancy in the numbers just noted may be partly explained as due to the lack of uniform distribution of the light

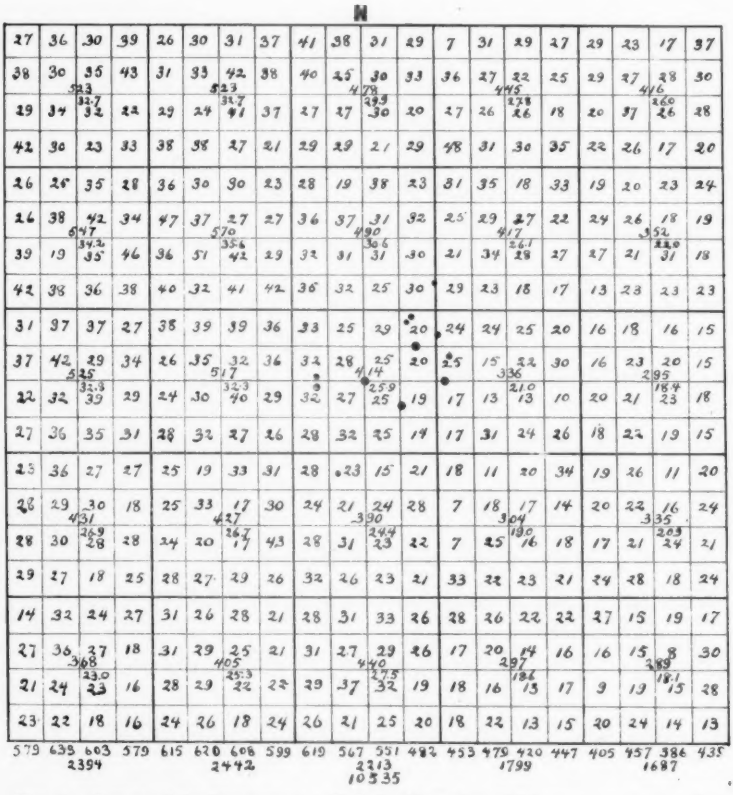


FIG. 3. Count of the Stars upon a Pleiades Negative of 7 hours exposure, taken with the 6-inch star camera of Goodsell Observatory. The small squares are 16′.2 by 16′.2.

from the objective over the entire area of the plate. It is impossible to focus equally well upon the central and the outer parts of the field of a lens at the same time. In the eight-inch the focussing was sharp for the center, but not perfectly sharp near the edges of the plate. This may account for the falling off of the numbers near the edges and especially in the corner blocks.

On the other hand, the Bruce telescope, having so much larger a field, (5° in diameter) may well be lacking a little at the center in order that the focus average well over the whole field.

We have found it necessary with our Brashear six-inch star-camera to sacrifice a little the sharpness at the center in order to distribute fair focussing over the field of 10° diameter. In order to test the effect of this upon the number of faint stars photographed I have made a similar count of the stars in the central portion of a plate of the Pleiades taken with the six-inch at the same time with that taken with the eight-inch, for which the count has just been discussed. The results are given in the cut Figure 3. The scale is about one third of that for the plates taken with the eight-inch; the squares are 16′.2 on a side and the area of each is 262′. Although the squares are nearly nine times as large the number of stars is only three times as great, so that the efficiency of this instrument for photographing faint stars is only one third of that of the eight-inch.

I have divided the area counted on this plate into blocks of four squares on a side, so that the central block is roughly the same as the four blocks around the center in Figure 2. At a glance one sees that the numbers increase toward the north and east, i. e., toward the Milky Way and that they decrease toward the west and south. Directly south of the Pleiades the numbers after decreasing increase again, indicating a faint cloud of the Milky Way in the background. The average per square in the central block comes out 25.9 while the average for the whole area is 26. 3showing a slight lack of faint stars within the group. I feel, however, that this is due to the better focussing some distance out from the center, and perhaps to some extent also to the greater density of the nebulosity impressed upon this plate in the vicinity of the four brighter stars. The total number of stars counted on this plate is 10535, within an area 5°.4 square. If the whole heavens were equally strewn with stars the grand total would be about 15,000,000.

On the whole the conclusion to be drawn from the two photographs is that the number of faint stars within the Pleiades group does not greatly exceed that in equal areas surrounding it. If we deduct from the count in Figure 2 about 150 stars which are bright enough to catch the eye easily in Figure 1, sixty of them must be taken from the central blocks and ninety from the outer blocks. The averages then become, for the central portion 8.6 and for the whole area 7.5. The cluster therefore probably does not include many of the fainter stars.

Another question which I wished to test was whether with our telescope the limit of effective exposure has been reached in any of the long exposures. Dr. Isaac Robert's in his splendid volume "Photographs of Stars, Star-Clusters and Nebulæ", Vol. II p. 21, makes this surprising statement:

"The group of the Pleiades has been photographed with the 20-inch reflector during numerous intervals between 1886 and

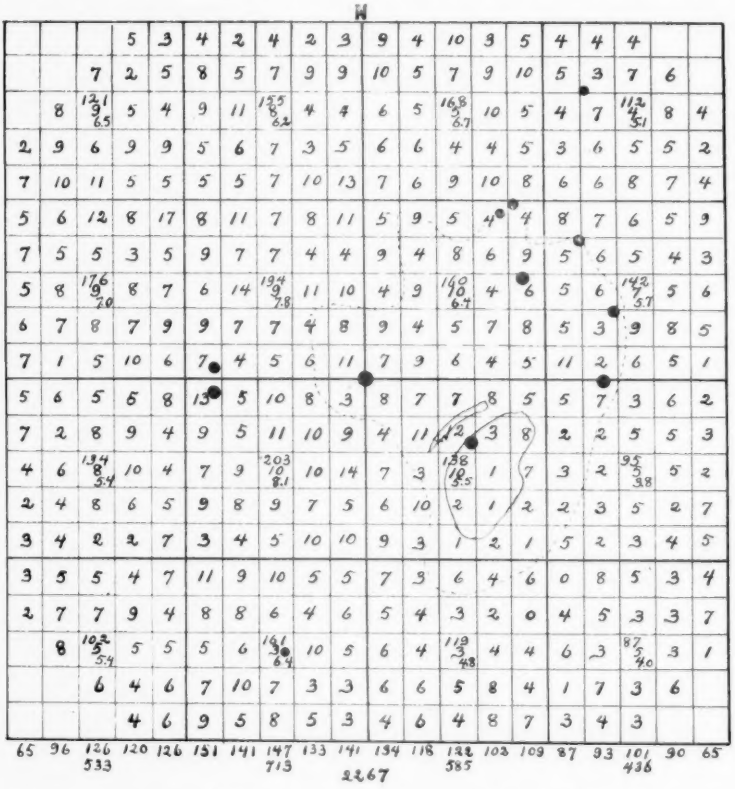


FIG. 4. Count of the Stars upon a Pleiades Negative of 4 hours exposure, taken with the 8-inch photographic telescope of Goodsell Observatory. The small squares are 5'.5 by 5'.5.

1898 with exposures of between one minute and twelve hours. The results are that only the same faint stars and nebulosity seen upon plates which have had an exposure of one-and-a-half hours are depicted upon those which have been exposed during ten or twelve hours."

Similar statements are made concerning photographs of the Great Nebula in Andromeda, the Great Nebula in Orion and of regions of the Milky Way. These are so at variance with my own results that I have wondered whether the difference could

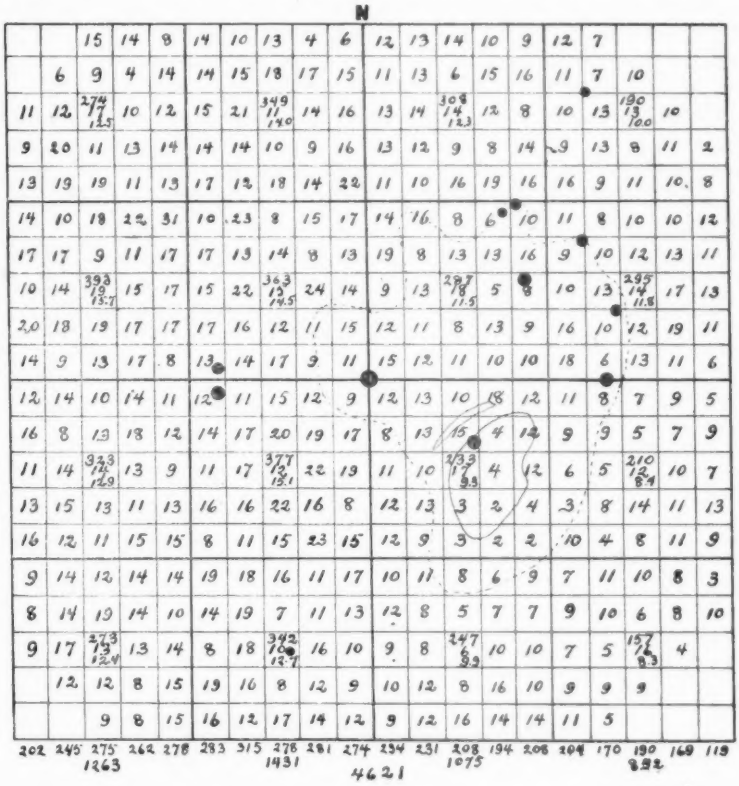


FIG. 5. Count of the Stars upon a Pleiades Negative of 16 hours exposure, taken with the 8-inch photographic telescope of Goodsell Observatory. The small squares are 5'.5 by 5'.5.

be due to the different character of the instruments used or to difference in transparency of the atmosphere at the two localities.

Figure 4 gives the count of another negative taken with the 8-inch telescope and an exposure of four hours. The total is 2267 stars, as against 3021 when the exposure was seven hours. The distribution of the stars is practically the same, every block showing a decrease of approximately two stars to the square.

Figure 5 gives the count upon a negative exposed for sixteen hours, with the 8-inch telescope, on the nights of October 30, 31, November 1 and 2, 1899. A glance at the numbers shows that they have increased largely on all parts of the plate over the corresponding numbers for the seven hour exposure. The largest number in any one square is thirty-one, where it was sixteen before, and the averages in all the blocks have increased by from three to six stars. In the central blocks the increase is not as great as in the outer blocks. The increase is least in the blocks which include the most of the nebulous area, indicating that with this long exposure the nebulous matter somehow, either on the plate or in the sky, interferes with the light from the faintest stars. The gap south of Merope is still lacking in faint stars, but the increase there is in about the same proportion as on the rest of the plate; so there seems to be no reason to think that we have reached the limit of effective exposure with the 8-inch telescope, or that we have penetrated to the boundary of the stellar universe. The total number on this plate comes out 4621, and if the whole sky were uniformly strewn with stars the total would be roughly 60,000,000.

One interesting conclusion which may be drawn from a comparison of the counts on these three long exposure photographs is that, apparently, other things being equal the number of stars revealed varies as the square root of the duration of exposure. The average numbers per square on the three photographs are almost exactly represented by the formula

$$N = 3\sqrt{t}$$

where N is the number and t is duration of exposure in hours. This is clearly shown in the following table:

Duration	Average per square	$3\sqrt{t}$
h		
4	5.9	6.0
7	7.9	7.9
16	12.1	12.0

If this formula should hold true for still longer exposures we could in a moment calculate the number of stars revealed by any given exposures, or, on the other hand, the necessary exposure, to raise the number of stars revealed to any desired total. For example our sixteen hour exposure gave a total of 60,000,000 stars for the entire heavens. To raise that total to 100,000,000 the duration of exposure 16^h must be multiplied by the square of $\frac{100}{60}$, or about 2.8, giving forty-five hours, or approximately ten night's work. To raise the total to a billion stars would multiply the forty-five hours by one hundred, requiring the use

of 1000 nights, or about ten years with such weather as we have on the average; and the plate must remain in perfect adjustment during the entire time!

Figure 6 gives the count of a photograph of the Pleiades taken on January 5 of this year with an exposure of forty minutes.

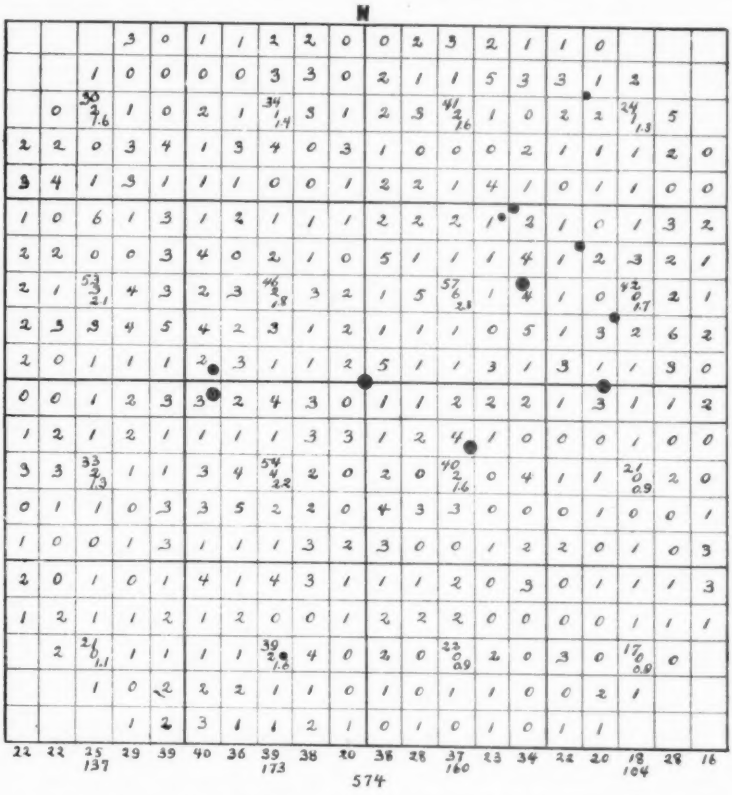


FIG. 6. Count of the Stars upon a Pleiades Negative of 40 minutes exposure, taken with the 8-inch photographic telescope of Goodsell Observatory. The small squares are 5′.5 by 5′.5.

The total number of stars on this plate is only 574 and the average per square for the whole plate 1.5, The average of the four blocks in the center is 2.0, showing plainly the clustering of of the brighter stars around Alcyone. This photograph shows even less stars than would be required by the formula of which we have just now spoken; for $3\sqrt{\frac{2}{3}} = 2.5$, while the count gives

an average of 1.5 per square. The sensitive plate used on this occasion was one which had been on hand for several months and may have lost its sensitiveness to a certain extent.

In order to see whether Dr. Roberts had really photographed more stars than our plates show, I made a count on a very fine positive, which he sent me in 1898, of his ten hour exposure. It is a very clear positive and evidently shows all the stars which were on the original negative, except near the bright stars where the halos and nebulosity screen off the faintest stars. The scale is almost the same as that of our plates (just a little smaller) so that the counts are comparable. I made the count in the same manner as on our own negatives, but omitted the squares on which the nebulosity was so dense as to hide the faint star images. The average for the remaining squares came out 9.6 per square, falling between those for our seven hour and our sixteen hour exposures. Curiously enough this number is also very near three times the square root of the exposure time in hours ($3\sqrt{10} = 9.5$), so that the 20-inch reflector appears to be no more effective in photographing faint stars than is our 8-inch refractor. It is, however, much more efficient in depicting the faint nebulous patches, and the inference just stated above is perhaps a very unsafe one, because of the possible loss of star-images in making the positive copy.

The longest exposure that I know of having been made by any one, is one on the Pleiades by W. Stratanoff, Taschkent, Russia, lasting twenty-five hours. This required the work of nine nights in December 1895. The instrument employed was a photographic telescope of thirteen inches (0.33 meter) aperture. In the *Astronomische Nachrichten* Band 144, p. 139, Mr. Stratanoff gives the count of the star-images upon this plate, covering an area of 4.35 square degrees, as 6614. He thinks that a considerable number of stars are hidden by the dense nebulosity around the bright stars on this plate and estimates the total at 6700 or 6750. This would make the number in 100 square minutes forty-three, or in 30.25 square minutes (the area of my squares) 13.0. This is only one star more per square than the number upon our sixteen hour plate.

In the following table I have put together for the sake of comparison the results of the different counts of which I have spoken in this paper all reduced to the same scale, as nearly as I could do it with the data at hand.

Exposure t h	Number of stars in Area 3°.20	Average per square. 5′.5 × 5′.5	$3\sqrt{t}$	Observer	Instrument.
⅔	574	1.5	2.4	Wilson	8-inch refractor
4	2267	5.9	6.0	Wilson	8-inch refractor
6	3178	8.5	7.3	Bailey	24-inch refractor
7	3021	7.9	7.9	Wilson	8-inch refractor
10	3667	9.6	9.5	Roberts	20-inch reflector
16	4621	12.1	12.0	Wilson	8-inch refractor
25	5000	13.0	15.0	Stratanoff	13-inch refractor.

THE SOLAR APEX.

THOMAS CURRAN RYAN.

FOR POPULAR ASTRONOMY.

It seems evident that neither motion alone, nor attraction alone, could serve the purpose of initiating, or preserving, order in the material universe. Reasoning from the present standpoint of the physicist, we conclude that the molecular attraction and repulsion and their resultant, molecular motion, are as old as the gaseous state of matter. Reasoning from observed phenomena we are forced to believe that molar motion and gravitation are as old as material forms.

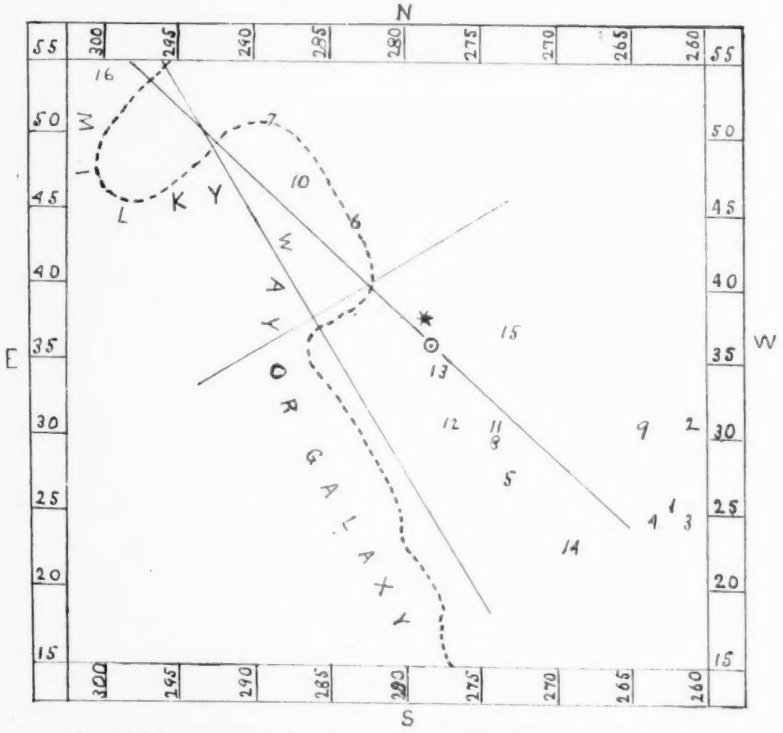
If two bodies come near enough to each other so that their attraction toward each other is greater than that of all bodies drawing them in other directions they will inevitably come into collision unless some motion upon a line divergent from the line of attraction is possessed by one or both of them. Nor will such divergent motion prevent the catastrophe unless, at the least, it be sufficiently swift and divergent to counterbalance attraction, and result in a compromise motion that will keep them revolving about their common center of gravity. Motion is the only curb upon gravitation; gravitation the only curb on motion. And unless both are curbed the conditions will not exist under which the laws of sidereal evolution can be manifested.

In 1802, in his investigation of binary star systems, Herschel observed the laws of gravitation and motion in operation beyond the solar system. Almost a century before this—1718—Halley, by comparing the places of Sirius and Arcturus in the sky with their positions upon a star map made as long ago as Ptolemy's time, detected the fact that, during two thousand years, Arcturus had moved over one degree, and Sirius about half as much. Since the application of the camera and spectroscope to the study of this subject a fairly large number of stars with real motions have been observed. These investigations have combined with what may be termed the necessity of the case to cause general belief that the stars are all endowed with motion.

Herschel was the first to prove that our Sun is no exception to this rule. He took as the basis of his calculations such proper motions of stars as were known in his day and available for the purpose. The result he obtained is denoted by the numeral (1) on the accompanying map. Hector Macpherson Jr., in his book, "A Century's Progress in Astronomy", says:

"Herschel's great discovery, from the apparent motions of the stars, of the movement of the solar system, was not accepted by the next generation of astronomers. Bessel declared in 1818 that there was absolutely no evidence to show that the Sun was moving toward Hercules. Even Sir John Herschel rejected his father's views."

So little was this discovery of Herschel credited by astronomers, that fifty-four years elapsed before one came upon the scene gifted with insight sufficiently keen to take up the subject



again. This was Argelander, who, as Mr. Macpherson tells us, "in 1837, in a memorable paper based on his observations at Abo, in Finland, attacked the problem, and demonstrated, from a discussion of the motions of 390 stars, quite independently of Herschel's work, that the solar system was moving toward Hercules."

After Argelander's presentation of the question, it was seriously taken up from time to time, by many astronomers. No two, however, have obtained precisely the same result.

In the inserted map the greater part of these results, and I think, about all of them that are deemed well worthy of credit among living astronomers, are designated by numerals. The numerals indicate the chronological order in which they were announced. The first four,—Herschel's (1), Argelander's (2), Airy (3) and Main (4) are now obsolete and are given here only because they possess historical interest. I have not attempted to trace the division lines between the three constellations, which occupy the portion of the sky covered by the map. They have no practical relation whatever to the problem, and the graphical lesson to be derived from the *ensemble* of results can be studied better without confusing the eye by unnecessary lines. The derived points of solar direction are situated as follows in the constellations:

Numbers 1, 2, 3, 4, 5, 9 and 14 in Hercules,
Numbers 6, 8, 10, 11, 12, 13 and 15 in Lyra,
Numbers 7 and 16 in Cygnus.

The map, barring that it does not attempt to show the convergence of the hour circles toward the north pole of the heavens, represents a region of the sky, bounded upon the north by declination circle 55+, upon the west by hour circle 260, upon the south by declination circle 15+, and on the east by hour circle 302½.

The numerals, 1 to 16 inclusive, show sixteen locations of the solar apex by different astronomers in chronological order, as follows:—

1	Herschel,	1783,
2	Argelander,	1837,
3	Airy,	1859,
4	Main,	1859,
5	Ludwig Struve,	1887,
6, 7	Lewis Boss,	1890,
8	Kapteyn,	1893,
9, 10	Oscar Stumpe,	1896,
11, 12	Newcomb,	1899,
13	Newcomb,	1903,
14, 15	Dyson and Thackeray,	1905,
16	Comstock,	1906.

The star in the center is Vega.

The diagonal straight line farthest to the left represents what might be called parallel seventeen north galactic latitude:—that is to say, it is believed to run parallel with the central line or plane of the Milky Way and to be seventeen degrees distant from that line.

The other diagonal straight line inclines away from the galaxy

at an angle of fifteen degrees, and is, approximately, the central line of the length dimension of the area occupied by twelve of the results noted upon the map, namely, numbers five to sixteen; the first four being, for reasons already stated, excluded from this computation.

The effect of these two diagonal lines, studied in connection with the length extension of the area occupied by the numerals, is to show that the general result of the investigation has been to push the solar apex north-eastward and into the Milky Way, the north-western boundary of which is represented upon the map by an irregular line.

The straight line crossing the two diagonal lines before mentioned points to the north and south poles of the galaxy, and may be taken as representing a meridian line of galactic longitude.

The tendency above mentioned is particularly emphasized by the very suggestive results shown by the numerals, 9, 10 and 16. The first was derived by Stumpe from stars of fourth magnitude, the second by the same investigator from stars of magnitude eight, and the last by Comstock from stars fainter and more distant than any before employed—9.5 and 10 magnitudes.

Professor Comstock, at the meeting of the Astronomical and Astrophysical Society of America, held in New York, December 27th to 29th, 1906, summed up the discordant results reached by different astronomers, in a paper entitled "The Apex of the Solar Motion." He represented the results graphically by lantern projection, classified with respect to the average brightness of the stars employed in the determination.

The extreme discordances, in galactic latitude, of the twelve results here considered are represented by Stumpe's (9) and Comstock's (16,) and amount to about sixteen degrees. On the other hand the difference in galactic longitude between Dyson and Thackeray's result (14) and Comstock's (16) is about forty-two degrees.

This variation in galactic longitude, says Professor Comstock, "is attributed to a small drift of the nearer stars parallel to the plane of the galaxy toward the constellation Cassiopeia. This is shared by most of the Sun's stellar neighbors and affects the bright stars in a larger measure than the faint ones because a larger percentage of the bright stars are included in this drift."

The accompanying map graphically illustrates the tendency of continued investigation to carry the apex toward the Milky Way. It also presents evidence that this tendency arises from

the use of more distant stars as a basis for calculations. Thus there is a difference of twelve degrees of galactic latitude between results (9) obtained by Stumpe from fourth magnitude stars, and (10) obtained by him at the same time from eighth magnitude stars. Again, there is a difference of seven and one half degrees of galactic latitude between result 10 and that obtained by Comstock (16) from stars of about tenth magnitude.

Dyson and Thackeray used stars of the first and second spectral types. From the first, stars of the Sirian type, they derived result (14) and from stars with solar spectra, result (15). This seems to be in accord with the general trend of investigation, the Sirian stars indicating an apex (14) four degrees nearer to the plane of the Milky Way than the solar stars. (15).

Thus far, almost all the stars employed in this class of investigations have been selected from the northern skies. It will be necessary to study the problem further by using southern stars as the basis of calculations. But almost all the astronomers of the world reside far north of the equator, hence our acquaintance with the proper motions of stars in the southern skies is only just beginning to be sufficient for this purpose.

When the solar motion shall have been studied from all parts of the heavens, it does not seem likely that the result will be a very marked deviation from present conclusions. The use of northern stars in the work probably "displaces the goal towards the equator", as Miss Clerke remarks. The use of faint stars evidently displaces it towards the plane of the galaxy. The analogue of this would be that the use of southern stars would displace the apex toward the north, while the use of faint southern stars would in a like manner move it in toward the galaxy.

Now if we study what the accompanying map shows as to the first mentioned of these analogues we will notice that a line drawn from sixteen through ten to nine though not exactly straight, is nearly so, and has a general inclination of about twenty-seven degrees from the plane of the galaxy. If we anticipate experiment by assuming that the proper motions of southern stars of fourth, eighth and tenth magnitudes, selected from the region of sky opposite to those which gave results nine, ten, and sixteen, shall tell us the same story, they might give us a line intersecting a straight line from nine to sixteen at a point about two degrees south by southwest from number six. That is to say: the southern stars may be suspected of disclosing a line of apices beginning with one derived from tenth magnitude stars situated say at R. A. 278, D + 16, and inclining north from the

plane of the galaxy at an angle of twenty-seven degrees to apices derived from eighth and fourth magnitude stars.

If Professor Comstock's explanation of the variation in galactic longitude, in the results obtained from northern stars, accounts for a considerable portion of that variation, say for the excess of variation in longitude over latitude, the distance between apices derived from southern stars of fourth, eighth, and tenth magnitudes would probably be less than that shown upon the map between results nine, ten and sixteen. But, if the analogue holds true, the angle of their inclination from the plane of the galaxy would be about twenty-seven degrees, and the two lines would intersect as above stated. Would not the point of intersection of such lines be taken as the solar apex? Time and experiment alone can tell whether the supposed analogue will prove a reality. But, if not this way, then by some other method of *combining results* and obtaining a mean from them, a final decision must apparently be reached. We can hardly hope to adopt as final any single solution that has been or may be obtained.

The mean of the twelve results before mentioned is indicated on the map by a dot surrounded by a small circle, about midway between thirteen and Vega. While the apices thus far derived are, at first glance, discordant, they seem to embody evidences of the manifestation of a law of tendency toward a common focus, which will not be far removed from the mean of those already found, but it is likely to be a little farther northeast, and about the same distance from the plane of the galaxy.

Wausau, Wisconsin.

A NEW DEVELOPMENT OF THE KINETIC THEORY OF GASES.

LUIGI D'AURIA.

For Popular Astronomy.

The substance of this paper was presented by the writer for the first time, somewhat tentatively, in a paper "On the kinetic theory of gases," read at the New York meeting of the American Association for the Advancement of Science, December 30, 1906, before the Physical Section, and its principal object is the development of the kinetic theory on purely mechanical ground, that is, independently of thermodynamics.

The problem of the kinetic theory involves the determination of all the physical properties which may be possessed by any very large collection of smooth, hard, small spheres with unit co-efficient of restitution, which without exerting any mutual force upon each other are darting about in all directions in a given amount of space bounded by a material surface from which they rebound without loss of energy. Maxwell pointed out the fact that when such a medium as this has acquired dynamical stability, or statistical equilibrium, each sphere, whatever be its mass, will have the same mean kinetic energy of translation, this being the only kind of energy which the spheres can possibly acquire. Clausius found that when the medium is in such condition of equilibrium the average distance traversed by a sphere between two successive encounters with the other spheres, which distance he called the *mean free path*, is the same for all the spheres, and pointed out that in the same medium this quantity varies inversely with the density, or directly with the volume occupied by the medium.

The next step in the development of the kinetic theory, after reaching the above conclusions, was to find the pressure exerted by the medium upon unit area of its bounding surface for which purpose Newton's second law of motion was applied with the result of finding the well-known expression

$$p = \frac{1}{3} \rho \overline{u^2} \qquad (1)$$

in which ρ is the density of the medium, and $\overline{u^2}$ the mean square of the speeds of the spheres, the square root of which is usually called the *mean square speed*. This expression, containing as it does all the elements in terms of which the mechanical properties of the moving sphere medium could be expressed is naturally regarded by physicists as the fundamental equation of the kinetic theory. It leads to

$$p V = \frac{1}{3} N m \overline{u^2} \qquad (2)$$

in which V is the volume of the medium, N the number of spheres contained by it, and m the mass of a single sphere; and since $\frac{1}{2} m\overline{u^2} = \bar{\epsilon}$ is the mean kinetic energy of translation of a sphere, and $N\bar{\epsilon} = E$ is the kinetic energy of agitation of the medium, equation (2) can also be expressed as follows:

$$p V = \frac{2}{3} N \bar{\epsilon}, \qquad (3)$$

$$p V = \frac{2}{3} E. \qquad (4)$$

This was as far as the kinetic theory could be developed on purely mechanical ground. The relation beeween the volume and the energy of the medium irrespective of pressure, and the relation between the pressure and the volume of the medium irrespective of its energy, were both left to be determined with the assistance afforded by thermodynamic principles applied to gases. For this it was necessary to assume that the moving sphere medium was really a gas and that the mean kinetic energy $\bar{e}$ of the spheres was the absolute temperature of such a gas. Thus, since on this latter assumption, equation (3) explains both Boyle's and Charles's laws, and since for gases which follow these laws thermodynamics furnishes the equations

$$V\bar{e}^{\gamma-1} = \text{constant}, \tag{5}$$

$$pV^{\gamma} = \text{constant}, \tag{6}$$

in which $\bar{e}$ represents the absolute temperature, and γ the ratio of the two specific heats; the two relations above mentioned are determined.

The thermodynamical expression for the ratio of the two specific heats of a gas is

$$\gamma = \frac{\delta E + p\delta V}{\delta E} = 1 + \frac{p\delta V}{\delta E} \tag{7}$$

and since from equation (4) we have

$$p\delta V = \frac{2}{3}\delta E$$

it follows $\gamma = \frac{5}{3}$, which is the well-known ratio of the two specific heats of a gas whose molecules can acquire only kinetic energy of translation like the spheres in our hypothetical medium.

The relations expressed by the two equations (5) and (6) are purely mechanical and should be determined on purely mechanical ground, without invoking thermodynamical principles. We know that if we take a mass of our moving sphere medium, bounded by a surface which is impervious to energy, and compress it into a smaller volume, we will have to expend a certain amount of energy W upon it, and that the result of the compression will be therefore to increase the mean kinetic energy of each sphere by the amount W/N. Kinematically, the diminution of the volume of the medium caused by the compression has for its immediate effect the shortening of the length of the mean free path of the spheres, a shortening which while a gas is being compressed must take place with a speed which is quite small

compared with the speed of the molecules. Putting together the kinetic and the kinematic effects of the compression we can readily see that a relation must exist between the mean kinetic energy and the mean free path of a sphere; and it appears to me that this relation, whatever it may be, can hardly be affected by supposing that each sphere of the medium were moving always in a path equal to the mean free path, in any direction, and with kinetic energy always equal to the mean kinetic energy of each sphere. With this supposition we can imagine each sphere, while the medium is being compressed, as if it was oscillating between two perfectly elastic parallel plates perpendicular to the direction of its motion while one of these imaginary plates is moving towards the other uniformly with speed which is very small compared with that of the sphere.

The kinetics of a smooth, hard, perfectly elastic sphere placed in the above conditions were investigated by the writer in the following simple manner.

Beginning from any instant of time when the oscillating sphere is just rebounding from the imaginary moving plate, the speed of which will be indicated by c, let us denote the speed which the sphere possesses at that instant of time, by u_1; and the path described by it until it reaches the other plate by h_1. The length of the second path described by the sphere will be shorter than h_1 by an amount

$$\delta h_1 = c t_1,$$

in which t_1 represents the period of time which intervenes between the first and the second encounter of the sphere with the moving plate, that is, the period of the oscillation of the sphere, which can be expressed by

$$t_1 = \frac{2h_1 - \delta h_1}{u_1}$$

Substituting the value of t_1 in the above expression for δh_1, we find

$$\delta h_1 = \frac{2 c h_1}{u_1 + c},$$

and therefore the length of the second path h_2 will be

$$h_2 = h_1 - \delta h_1 = h_1 \frac{u_1 - c}{u_1 + c}.$$

The two paths h_1 and h_2 of the first oscillation of the sphere are both described with speed u_1 and therefore the mean path described with this speed is

$$s_1 = h_1 - \frac{1}{2} \delta h_1 = h_1 \frac{u_1}{u^1 + c}.$$

The speed of the sphere during its second oscillation becomes

$$u_2 = u_1 + c$$

and the two paths described by it in this oscillation are h_2 and

$$h_2 - \delta h_2 = h_3$$

in which

$$\delta h_2 = ct_2,$$

and

$$t_2 = \frac{2h_2 - \delta h_2}{u_2}.$$

Substituting this in the previous equation we find

$$\delta h_2 = \frac{2c\,h_2}{u_2 + c},$$

and

$$h_3 = h_2 - \delta h_2 = h_2 \frac{u_2 - c}{u_2 + c} = h_1 \frac{u_1 - c}{u_1 + c} \times \frac{u_2 - c}{u_2 + c};$$

and the mean path of the second oscillation of the sphere is

$$s_2 = h_2 - \frac{1}{2}\delta h_2 = h_2 \frac{u_2}{u_2 + c} = h_1 \frac{u_1 - c}{u_1 + c} \times \frac{u_2}{u_2 + c}.$$

Proceeding in the same manner we find the following values for the mean paths corresponding to the third, fourth, fifth, etc., oscillation:

$$s_3 = h_1 \frac{u_1 - c}{u_1 + c} \times \frac{u_2 - c}{u_2 + c} \times \frac{u_3}{u_3 + c};$$

$$s_4 = h_1 \frac{u_1 - c}{u_1 + c} \times \frac{u_2 - c}{u_2 + c} \times \frac{u_3 - c}{u_3 + c} \times \frac{u_4}{u_4 + c};$$

$$s_5 = h_1 \frac{u_1 - c}{u_1 + c} \times \frac{u_2 - c}{u_2 + c} \times \frac{u_3 - c}{u_3 + c} \times \frac{u_4 - c}{u_4 + c} \times \frac{u_5}{u_5 + c};$$

etc,.....

Multiplying and dividing the expressions found above for s_1 and s_2, the first by $u_1 - c$, and the second by u_1; and making the proper reductions in the expressions for s_3, s_4, s_5, etc., we get

$$s_1 = \frac{h_1 u_1 (u_1 - c)}{u_1^2 - c^2}; \quad s_2 = \frac{h_1 u_1 (u_1 - c)}{u_2^2 - c^2}; \quad s_3 = \frac{h_1 c_1 (u_1 - c)}{u_3^2 - c^2};$$

$$s_4 = \frac{h_1 u_1 (u_1 - c)}{u_4^2 - c^2}; \quad s_5 = \frac{h_1 u_1 (u_1 - c)}{u_5^2 - c^2}; \text{ etc.}$$

Hence we have

$$s_1 (u_1^2 - c^2) = s_2 (u_2^2 - c^2) = s_3 (u_3^2 - c^2) = \ldots\ldots\ldots = s (u^2 - c^2) = \text{constant};$$

and when c is very small compared with u we can write:

$$su^2 = \text{constant.}$$

We have also, therefore,

$$se = \text{constant,} \qquad (8)$$

in which e represents the kinetic energy of the oscillating sphere, and hence the following theorem:

The kinetic energy of a smooth, hard, and perfectly elastic sphere which is forced to oscillate between two perfectly elastic, parallel plates perpendicular to the direction of its motion while one of these plates is moving towards the other with uniform speed which is very small compared with that of the sphere, varies inversely with the length of the path described by the sphere while oscillating between the plates.

Concerning the application of this theorem to the spheres which constitute our hypothetical medium it may be observed that while for any one of these spheres the products $s_1 e_1$, $s_2 e_2$, $s_3 e_3$,.....taken successively are probably quite different from one another, yet if a very long series of such products were taken and then divided into groups each containing a number n of observations large enough to make $\frac{1}{n} \Sigma (s)$ equal to the mean free path and $\frac{1}{n} \Sigma (e)$ equal to the mean kinetic energy, then $\frac{1}{n} \Sigma (se)$ would be found sensibly equal to $\overline{se} = \text{constant}$. Thus we can see that the above theorem when applied to the spheres of the medium in question must give results at least very closely approximated to the truth. Admitting then that in this medium $\overline{se} = \text{constant}$, and observing that $\overline{s}$ varies directly with the volume V of the medium we can write:

$$V\bar{e} = \text{constant;} \qquad (9)$$

and also

$$VE = \text{constant.} \qquad (10)$$

Here we have a new fundamental equation from which we get

$$dE = E \frac{dV}{V},$$

in which dE is the increase in the kinetic energy of the medium corresponding to the diminution of volume dV. The latter involves an expenditure of energy pdV in which p is the pressure

exerted by the medium upon unit area of its bounding surface. Hence we must have

$$pdV = dE = E\,\frac{dV}{V},$$

$$pV = E, \tag{11}$$

and substituting in this the value of E from (10),

$$pV^2 = \text{constant}. \tag{12}$$

Denoting by M the mass of the medium and by $\bar{u}$ the mean square speed of the spheres we can put

$$E = \frac{1}{2}\,M\,\overline{u^2}$$

and with this value of E our equation (11) furnishes

$$p = \frac{1}{2}\,\frac{M}{V}\,\overline{u^2} = \frac{1}{2}\,\rho\,\overline{u^2}. \tag{13}$$

It will be observed that without the least reference to thermodynamic principles we have been able to find all the mechanical properties of the moving sphere medium. Our equations (9) and (13) correspond to the thermodynamic equations (5) and (6); and if this medium adequately represents a gas the ratio of its two specific heats will have to be $\gamma = 2$ instead of $\frac{5}{3}$. This latter value is based upon the fundamental equation (1) of the kinetic theory supposed to involve Newton's second law of motion, while the value $\gamma = 2$ is a direct result of the application of my new theorem to the kinetic theory leading to new equations from which the expression (13) for the gaseous pressure is derived. This expression it will be noticed, differs from (1) only in the numerical coefficient.

In a correspondence recently had concerning the conclusions reached in this paper, a prominent American physicist says: "If the conclusions reached by you are correct it necessarily follows that the generally accepted views are in error. In a case of such importance it seems to us that an article on the subject should take account in advance of the criticisms which would probably be directed against it, and should not merely obtain a result different from that previously obtained, but should show in what way previous investigators were in error." Taking the opinion just quoted as representing the attitude which most men of science would take towards so important a change in the kinetic theory as my investigation implies, I accepted the challenge and boldly began to search for the error involved in the

method employed by previous investigators to find the expression (1) for the gaseous pressure which is supposed to be based upon Newton's second law of motion. The results which I have found in this search will be published shortly in a separate paper, but I can confidently announce that they confirm the conclusions which I have reached in the present paper, and point out that, as far as the gaseous pressure from the kinetic theory stand point is concerned, Newton's second law of motion has never been properly applied.

Philadelphia, Penn.

THE STUDY OF VARIABLE STARS.

J. MILLER BARR.

No department of Astronomy is more attractive than that which deals with the wonderful phenomena of stellar variation. It may, further, be claimed for this study that it is peculiarly adapted to the needs of amateurs, since a great number of known variables (including all the brighter and more interesting objects) can be well observed with small instruments. Indeed, an ordinary field-glass will suffice, not merely for the study of many known variables, but for the discovery of new ones. It is hoped that the present imperfect review of this subject will not be devoid of interest to amateur observers.

EARLY OBSERVATIONS

The earliest known observations on the brightness of the stars are those recorded in Ptolemy's *Amalgest.** There is some uncertainty as to the origin of Ptolemy's star-magnitudes; but they are probably due to Hipparchus, whose catalogue of stars (the first on record) was prepared more than 2,000 years ago. Of greater value are the careful estimates of stellar magnitude made by the Persian astronomer Al-Sufi, about the middle of the tenth century.† Our present knowledge regarding the "secular variation" of certain stars‡ is based largely upon a comparison of Ptolemy's and Al-Sufi's magnitudes with those determined by modern astronomers.

* The *Amalgest* was written in the second century of our era.

† Al-Sufi's "Description of the Fixed Stars" has become known to us chiefly through Schjellerup's translation, published in 1875.

‡ Much valuable information on this subject will be found in Mr. Gore's papers on "Changes in the Stellar Heavens" (*Observatory*, Oct. 1900 to Jan. 1901, also Jan. 1902), and "The Secular Variation of Starlight" (*Ibid*, Nov. 1903).

Thus the well-known star β Leonis (whose present magnitude is about 2.2) was rated as of the *first* magnitude by Ptolemy, Al-Sufi and Tycho Brahe (16th century). A case yet more remarkable is that of θ Eridani, which Al-Sufi placed in the first rank, though it is now of the third magnitude only. Among the stars which "have probably increased in brightness since Al-Sufi's time" are α Ophiuchi, β Eridani and δ Sagittæ.

NEW STARS

Although the so-called "new" or temporary stars differ much from ordinary variables, they are properly classed with the latter, and are hence included in our more extensive lists of these objects. The outbursts of such bodies, as recorded in ancient times, represent, therefore, the beginnings of that branch of Astronomy with which we are concerned.

The following list includes all known objects of this class. For stars revealed by photography* the constellation name is printed in italics; the date in each case being that of discovery.

134 B. C.	Scorpio	1860	Scorpio
123 A. D.	Ophiuchus	1866	Corona
173	Centaurus	1876	Cygnus
386	Sagittarius	1885	Andromeda
389	Aquila	1890	*Perseus*
393	Scorpio	1892	Auriga
827	Scorpio	1893	*Norma*
1012	Aries	1895	*Carina*
1203	Scorpio	1895	*Centaurus*
1230	Ophiuchus	1899	*Sagittarius*
1572	Cassiopeia	1900	*Aquila*
1604	Ophiuchus	1901	Perseus
1670	Vulpecula	1903	*Gemini*
1848	Ophiuchus	1905	*Aquila*

Three celebrated objects are included in this list, viz., the "star of Hipparchus" (134 B. C.), Tycho Brahe's star (1572), and Kepler's Nova of 1604.

In the famous "Pilgrim Star" of 1572 we have the most striking instance of stellar variation on record. In November, 1572, this star rivalled Venus in brightness, and was distinctly visible in the daytime. It remained in view for about sixteen months, its color changing from white through yellow and red to a bluish tint. The great star of 1604 equalled Jupiter in brilliancy, and faded to invisibility in fourteen or fifteen months.

* With one exception, these stars were discovered by Mrs. Fleming, at Harvard. The exception is *Nova Geminorum*, discovered by Professor Turner at Oxford in 1903.

The story of *Nova Persei*, 1901—the great new star of the twentieth century—is doubtless familiar to many of my readers. At the time of its discovery by Dr. Anderson of Edinburgh (February 22, 1901), this star was between the second and third magnitude. On the evening of February 23 it was brighter than Capella, but soon faded, becoming invisible to the naked eye in the course of a few months. The changes in its spectrum were most interesting, and a similar remark will apply to the *periodical* fluctuations observed in its light. It will suffice to add here that the study of this star, and of the wonderful nebula which surrounded it, has afforded much light on the complex problems presented by the Novæ.

VARIABLES OF LONG PERIOD

The typical star of this class is the famous variable *o* Ceti (Mira), whose fluctuations were first noticed by Fabricius in 1596. In the seventeenth century these light changes were carefully watched by several observers, and their *periodicity* was fully established. Boulliaud, in 1667, found the star's period to be 334 days. This is a fair approximation to the *mean* period, as given in recent catalogues, viz., 331.69 days.

Like other stars of its class, Mira Ceti varies through a wide range—the *maxima* being more sharply defined than the *minima*. At maximum brightness it reaches the third, and sometimes the second, magnitude; descending to 9.5 magnitude at minimum. Its usual color is a rich orange-yellow, becoming pale near maximum; the spectrum showing dark bands and bright lines, such as are found in many objects of this class. This spectrum (as photographed at the Lick Observatory) has been carefully studied by Professor Campbell.* Spectrograms taken at considerable intervals reveal striking changes, which (apart from other evidence) point clearly to the physical nature of the star's light-variation. The "underlying cause" is still unknown.

The variables of long period form a numerous and important class. Many red stars, with banded spectra, are found among them; a notable instance being the "crimson" variable R Leporis. Their light changes are always more or less irregular; the rise to maximum being usually more rapid than the fall to minimum. In some cases the deviations from regularity are very conspicuous: the well-known variable R Coronæ (discovered by Pigott in 1795) is an example of this kind.

* *Astrophysical Journal*, January 1899, p. 31.

A far more striking instance of irregularity is afforded by the wonderful southern variable η Argûs.* This star has been happily described as a "connecting link" between the "new" stars and ordinary variables. Its fluctuations were first noticed by the traveller Burchell in 1827. Although now invisible to the naked eye, it outshone Rigel in 1837-38, and was nearly or quite equal to Sirius in April, 1843. It is located in the great Argo nebula, in one of the richest regions of the sky.

VARIABLES OF SHORT PERIOD

The discovery of *rapidly-recurring* changes in stellar lustre was one of the notable achievements of the eighteenth century. Goodricke, in 1783, found that the fluctuations in the light of Algol were thus periodic;† and he pointed out that these changes were such as would result from the intervention of a dark body revolving about the star. The period of Algol, as given by Goodricke (viz., 2d. 20h. 48m.), differs from the true value by less than one minute.

To the same observer we owe the discovery, in 1784, of the light changes of β Lyræ and δ Cephei—the chief representatives of two diverse types. Both stars are regularly variable, the former in a period of about 12d. 21h. 59m., the latter in 5d. 8h. 48m. The light curve of β Lyræ is nearly symmetrical. It exhibits two unequal minima, such as would result from the mutual eclipses of two Suns, unequal in size and brightness, and revolving nearly in contact with one another‡. The light curve of δ Cephei resembles those of some long-period variables—the *increase* of light being more rapid than the *decrease*. Variation of this kind can only be attributed to physical changes—depending in some way upon the action of a close revolving satellite. A similar remark may apply to the Antalgol or "cluster" variables, which remain at or near minimum brightness for a large part of each period. The star 14.1904 Cygni (discovered by Ceraski in 1904) is a highly interesting example of this type: the interval between successive maxima being only about 3h. 14m.

Stars of the Algol and β Lyræ types have been conveniently designated as "eclipse-variables." Many interesting objects of this class have been brought to light in recent years. Among them is W Ursæ Majoris—noted for its short period of 4h 0.2m.:

* Otherwise known as η Carinæ.

† Montanari in 1669 discovered the light-changes of Algol, but failed to recognize their *periodicity*. The Arabic name Al-gol (the Spirit of Demon) suggests that these changes had been detected at a much earlier period.

‡ Cf. Myers, "The System of β Lyræ," *Astrophysical Journal*, 1898, p. 1.

and the Algol stars RW Tauri and Z Draconis, which are notable for the large range of their light changes.

With few exceptions, the eclipse-variables are white stars of Secchi's first type; while those of the δ Cephei class are yellow stars with second-type spectra. As regards distribution, the eclipse-stars are met with in all parts of the sky. On the other hand, stars of the δ Cephei class are (like the temporary stars) found chiefly in the Galaxy and its immediate vicinity.

METHODS OF OBSERVATION

Sir Wm. Herschel was the first to determine with accuracy the relative brightness of the stars.* The "method of Argelander," now so familiar to astronomers, is in fact but a modification of Herschel's original plan—the chief difference being in the system of notation.

Argelander's method may be thus described:—Let *v* denote a known or suspected variable, *a* an adjacent "comparison-star." The comparison is effected by glancing back and forth, from one star to the other, several times. If they are judged to be equal, the observation is recorded as

av or *va*,

either form denoting equality. If one of the stars appears very slightly—just perceptibly—brighter than the other, the interval may be called *one step* or *grade*, and the observation is written

*a*1*v* or *v*1*a*,

according as *a* or *v* is the brighter. If one star appears very slightly, but quite distinctly, brighter than the other, the interval may be called *two grades* (or steps), and the observation is recorded

*a*2*v* or *v*2*a*,

the brighter star being named first. Successively increasing intervals are designated as *three grades*, *four grades*, etc., and are similarly recorded.

It is necessary to point out that fluctuations, more or less evident, in the relative light of *a* and *v* will occur, owing to atmospheric waves or inequalities. If, however, the stars are fairly close together (say less than 1° apart), these changes will, under good conditions, be scarcely perceptible. In any case the stars should be compared repeatedly—not less than ten or twelve times—the mean or general result of the observations being then recorded, in the manner already described.

* Herschel's observations of the Flamsteed stars have been reduced and published at Harvard Observatory (H. C. O. *Annals*, Vols. XIV. and XXIII.)

The "step" or "grade" is of course an arbitrary quantity, but with practice one may acquire a fairly uniform scale. In general, this scale will vary for different observers, and also, with the same observer, for bright or faint stars. The value of a grade may, in any given case, be found from a comparison of the observations with the photometric magnitudes of the stars observed. Various methods of reduction are available, of which the details cannot with advantage be given here.*

Much will depend upon the choice of suitable comparison-stars. In general, several stars should be used, some a little brighter, some a little fainter, than the variable. Light-intervals not exceeding four grades may be estimated with considerable precision, and for such intervals fractions of a grade should be recorded. The accuracy of the comparisons diminishes rapidly with increasing light intervals, and also with increasing angular separation of the stars compared. If the latter are unlike in color, this will also tend to diminish the precision of the observations.

As regards instruments, a three-inch refractor will suffice for the observation of stars as faint as magnitude 9½; a six-inch for stars down to the eleventh magnitude. The brighter variables, such as Algol, Betelgeuse, etc., are best observed with the naked eye. For fainter stars—say from magnitude four to magnitude seven or seven and one half—an opera or field-glass will give better results than a telescope.

The following hints are based upon the writer's experience with an ordinary binocular:—Each star-image in turn, is brought *quickly* to the center of the field, and held steadily for about five to ten seconds, during which time it is viewed with close attention. Special care should be taken to observe each star (of the pair under comparison) in the *same manner e g.*, if the eyes are directed a little to one side of star *a* (which is often advantageous, especially with faint stars), they should be *similarly directed* with reference to star *b*. Attention to these details will add much to the value of the observations.

Many observers have been troubled with a subjective source of error, depending upon the relative position of the stars compared. If the comparison-stars are well distributed, such errors will be nearly eliminated from the final result. But suitable comparison-stars are not always to be found, especially for vari-

* For further information the reader may consult Mr. Yendell's valuable papers "On the Observation of Variable Stars," (POPULAR ASTRONOMY, Oct. 1905, Nov. and Dec. 1906). The second and third of these papers give full details concerning the reduction and discussion of observations.

ables having a small light-range. Much better results might be secured with the aid of a specially constructed binocular, fitted with two double eyepieces—one giving an *erect*, the other an *inverted*, image. These eyepieces (with the help of suitable devices) would be used alternately: the mean result of the observations would then be free from systematic error. Other special devices are available for the same purpose, and also for the comparison of stars differing widely in brightness. It is hoped that the new methods here referred to will form the subject of a future communication to the Royal Astronomical Society of Canada.

Photometric work on the stars has hitherto been left in the hands of professional astronomers. But I should like to emphasize the fact that a small telescope, fitted with a good photometer, would serve for the *accurate* observation of all stars within effective range of the instrument. The "photographic method" is also available for many amateurs. Its capabilities are shown by recent discoveries in this field, as described below.

PHOTOGRAPHIC METHODS

During recent years the progress in this branch of astronomy has been most rapid and striking. The application of photography—more especially at Harvard—has led to the wholesale discovery of new variables. These are, with few exceptions, faint telescopic stars. They are especially numerous in the great nebulous regions of Scorpio, Ophiuchus, and Orion, and in the Small Magellanic Cloud. The latter is the richest region in the heavens hitherto examined; about 1,000 variables having been found within its boundaries. More than 500 of these objects have been found by Professor Bailey in some of the globular star-clusters. The great cluster ω Centauri—the finest in the heavens—alone contains 128 variables.

These discoveries (which bring the number of known variables up to more than 3,000) have suggested an ambitious plan for a "Durchmusterung of variable stars."* This would include all variables down to the sixteenth magnitude (maximum brightness). The scheme, if carried into effect, will involve the coöperation of many astronomers, and the scrutiny of some fifty million star-images on photographic plates taken for the purpose.

Results of equal importance have been secured in the field of spectrum-photography. The orbital motion of Algol was demonstrated in 1888 by the periodic oscillation of dark lines in its spectrum—as photographed at Potsdam. This spectrographic

* *H. C. O. Circular* No. 116; POPULAR ASTRONOMY, Oct. 1906.

method has since been applied to β Lyræ, δ Cephei, and other short-period variables of various types. In each case, the variable has proved to be a close binary system in rapid motion.*

ORIGIN OF BINARY STARS

The discoveries just cited bring us into touch with one of the most interesting problems of modern Astronomy—that of the genesis of stellar systems. The theory of tidal evolution, as propounded by Darwin and extended by See, affords a satisfactory solution of the problem.† According to that theory, the components of each revolving pair were formerly united; their separation having been brought about by the rapid rotation of the original mass, due to its gradual condensation. Owing to tidal friction, the bodies thus formed by disruption of the parent mass would, in course of time, become more and more widely separated. Thus the closer spectroscopic binaries, such as β Lyræ or Algol, represent early stages in the evolutionary process; while the visual pairs (whose periods range from a few years to several centuries) exemplify much later stages in the same process. An important confirmation of this theory is afforded by recent researches on the period and light curve of β Lyræ.‡

CATALOGUES OF VARIABLE STARS

Schönfeld's first catalogue of variable stars—prepared in 1865—included 113 objects. This was revised and extended in 1875, the second list containing 143 variables. Chandler's first catalogue of 225 variables appeared in 1888. It was followed a few months later by the publication at Harvard of an "Index to Observations of Variable Stars" (H.C.O. *Annals*, vol. XVIII., No. viii.). This work contained "a catalogue of 225 variable stars, and references to 125,750 observations of them, made during the years 1858 to 1888." Chandler's second and third catalogues of these objects appeared in 1893 and 1896 respectively. The later list contains descriptions of 393 stars.

A well-known amateur astronomer, Mr. J. E. Gore, has given special attention to the unconfirmed or suspected objects of this nature. Such cases were brought together in 1885, in his "Catalogue of Suspected Variable Stars."

* A similar remark will apply to certain irregular variables—e. g., u Herculis.

† See Darwin's masterly address on "Cosmical Evolution," delivered before the British Association at the meeting in South Africa, 1905 (*Observatory*, Sept., Oct. and Nov., 1905).

‡ "Note on the Increasing Period of β Lyræ," by Dr. Alex. W. Roberts (*Observatory*, Feb. 1906 p. 98). See also the *Observatory* for Nov. 1905, p. 407. The period of β Lyræ, as given in the present paper, corresponds to the epoch 1900.0.

Within the past few years, two notable additions to the literature of this subject have appeared, viz., the Harvard "Provisional Catalogue of Variable Stars," and Father Hagen's *Atlas Stellarum Variabilium*. The last mentioned work is a *magnum opus*, of great value to all students of the subject.

Passing over the catalogues and ephemerides of variables which appear annually in different countries, I may refer to two very important works which have been in course of preparation for years, and will soon appear—one in Europe, the other in America. The American work under the title "A Bibliography of Variable Stars," will appear as a volume of the Harvard *Annals*. It will contain references to more than three thousand objects, with ample details, such as will render it invaluable to all astronomers. The European catalogue, it is understood will be equally comprehensive. It is being prepared by a committee of the Astronomische Gesellschaft, consisting of four eminent astronomers—Dunér, Hartwig, Müller and Oudemans.

CLASSIFICATION

Several attempts have been made to classify the variable stars; but a scientific system of classification, in harmony with the chief deductions of theory, as well as the facts of observation, is still wanting. The best-known system is that formulated by Professor E. C. Pickering in 1880, and reproduced (with slight additions) in his "Provisional Catalogue of Variable Stars" (1903). This includes five classes, two of which are subdivided, as follows:—

	EXAMPLES
I. New or temporary stars	Nova, 1572
II. Variables of long period;	
a. Ordinary stars of this class	o Ceti.
b. Stars subject to "occasional sudden and irregular outbursts of light which gradually diminishes"	U Geminorum.
III. "Variables of small range or irregular variation, according to laws as yet unknown"	α Orionis.
IV. Variables of short period;	
a. "Ordinary" cases	δ Cephei.
b. Stars with "minima successively bright and faint"	β Lyræ.
V. Stars of the Algol type	β Persei.

The leading star of each class is here mentioned. Some of the recently discovered Algol stars exhibit *secondary minima*: such stars should evidently form a sub-division of Class V. Class IV should be further sub-divided: one new division would include the Antalgol or "cluster" variables, another would contain those stars for which the *decrease* in light is more rapid than the *increase*. The inclusion of *all* variables of small range in Class III is clearly illogical.

A SHORT LIST OF VARIABLE STARS

I give below a list of the more interesting variables—such as can be studied with advantage by amateur observers. The periods and other data are derived chiefly from the Harvard "Provisional Catalogue," already cited. This work, which gives the positions and elements of 1227 stars, should be in the hands of every amateur.

Most of the stars in this list may be identified with the aid of a good Star-Atlas. The times of maximum and minimum brightness, for a majority of these stars, may be found from the monthly ephemerides in POPULAR ASTRONOMY or from the similar tables in the annual "Companion to the *Observatory*."

NAME	LIMITING MAGS.	PERIOD			CLASS	DISCOVERER	
		d	h	m			
U Cephei	7.0– 9.2	2	11	49.6	V.	W. Ceraski	1880
o Ceti	1.7– 9.5	331.7			II.	Fabricius	1596
ρ Persei	3.4– 4.2	Irr.			III.	Schmidt	1854
6.1904 Cephei	8.6– 9.1	32.3			V.	Blajko	1904
β Persei (Algol)	2.1– 3.2	2	20	48.9	V.	Montanari	1669
λ Tauri	3.3– 4.2	3	22	52.2	V.	Baxendell	1848
W Eridani	8.1–<12.5	369			II.	Fleming	1898
RW Tauri	8–11	2	18	27.2	V.	Fleming	1905
R Leporis	6–8?	436.1			II.	Schmidt	1855
α Orionis	1– 1.4	Irr.			III.	J. Herschel	1840
U Orionis	5.8–12.3	375			II.	Gore	1885
η Geminorum	3.2– 4.2	231.4			III.	Schmidt	1865
T Monocerotis	5.7– 6.8	27.0			IV.	Gould	1871
ζ Geminorum	3.8– 4.3	10	3	41.5	IV.	Schmidt	1847
R Geminorum	6.6–13.3	370.2			II.	Hind	1848
R Canis Maj.	5.7– 6.3	1	3	15.8	V.	Sawyer	1887
S Cancri	8.0–10.2	9	11	37.8	V.	Hind	1848
S Antliæ	6.3– 6.8	0	7	46.8	IV.	Paul	1888
W Ursæ Maj.	7.9– 8.6	0	4	0.2	V.?	Müller & Kempf	1903
R Leonis	4.6–10.5	312.8			II.	Koch	1782
R Hydræ	3.5– 9.7	425.1			II.	Montanari	1670
δ Libræ	5.0– 6.2	2	7	51.4	V.	Schmidt	1859
α Herculis	3.1– 3.9	Irr.			III.	W. Herschel	1795
U Ophiuchi	6.0– 6.7	0	20	7.7	V.	Gould	1871
X Sagittarii	4.4– 5.4	7	0	17.1	IV.	Schmidt	1866
R Scuti	4.8– 7.8	Irr.			III.	Pigott	1795
β Lyræ	3.4– 4.1	12	21	59.2	IV.	Goodricke	1784
χ Cygni	4.5–13.5	406.0			II.	Kirch	1686
η Aquilæ	3.7– 4.5	7	4	14.0	IV.	Pigott	1784
S Sagittæ	5.5– 6.1	8	9	11.8	IV.	Gore	1885
14.1904 Cygni	10.7–11.6	0	3	14.2	IV.	Ceraski	1904
Y Cygni	7.1– 7.9	1	11	57.5	V.	Chandler	1886
δ Cephei	3.7– 4.6	5	8	47.7	IV.	Goodricke	1784
U Pegasi	9.3– 9.9	0	8	59.7	IV.	Chandler	1894

St. Catharine's, Ontario, Oct 31, 1906.

ASTRONOMY IN THE HIGH SCHOOL, V.

Latitude and Time.

MARY E. BYRD.

FOR POPULAR ASTRONOMY.

Latitude, longitude and time are the names of the three great practical problems in astronomy which are most intimately connected with the affairs of daily life. Logically they may be reduced to two; for to determine longitude is to find local times. The whole problem is, however, somewhat complicated and it is best perhaps to omit it from an elementary course. While as yet this course has no fixed content generally recognized, enthusiastic teachers must be on guard against pressing some of the more difficult problems that appeal to them and thus neglect or crowd out simple, fundamental observations which are essential if the students's course is to be strong and well balanced.

The apparatus required to determine latitude and time need not be elaborate or expensive, but like all laboratory equipment, it must receive care and thought, and should be in readiness for use when the class begins to observe. The following simple appliances, mostly home-made, have been used by hundreds of students in getting their first practical knowledge of latitude and time: gnomon uprights of different height; carpenter's level, plumb lines, supported in different ways; horizontal sun-dial; and an altazimuth instrument called the Circles, made out of an upright shaft; a vertical and a horizontal circle. For instruments like these it is essential to have a meridian line carefully established on a fixed stone or platform.*

Observations for latitude are naturally among the first to be taken as they consist largely in measuring the meridian altitude of some heavenly body or finding the length of the shadow cast at noon by the gnomon post. To obtain the most accurate measures of altitude with the circles, the vertical circle must be carefully adjusted with its zero line, from which altitudes are reckoned, as nearly horrizontal as possible. Four readings should be taken, two with the vertical circle, for example, facing east, and two after it has been turned 180 degrees in azimuth, and faces the west. The time of observing should lie within a few minutes of the instant when the body chosen crosses the celestial

* See also Article III of this series and Chapter II of the writer's Laboratory Manual in Astronomy.

meridian. Any meridian altitude carefully measured may be used to find latitude, whether it be of the Sun, a planet or bright star.

Two things are essential in using the gnomon to find latitude. Its shadow must fall on a plane level surface, and the upright itself be at right angles to this surface, that is vertical. White paper fastened with a little paste on the stone or platform where the end of the shadow will come makes it appear more distinct. All preparations should be finished a minute or two before Sun noon, and the assistant give warning fifteen or twenty seconds beforehand, so that the observer may be in readiness with pencil in hand to mark the end of the shadow when "time" is called. This mark is perhaps best placed midway between the dark part of the shadow and the end of its penumbra. Three readings taken of the length of the shadow, and three of the height of the gnomon complete the observation.

"At Smith College Observatory, Northampton, Mass., November 2, 1905, the shadow of the gnomon upright, No. 8, was marked at Sun noon on the second meridian stone to the south, in order to determine approximately the latitude of the place."

All measures were made with a centimetre scale, and as the stone had settled a little, the height of the gnomon box above it, 5.1 cn., was added to the length of the upright above the box 65.5 c.n., making the entire height of the gnomon 70.6 cn. In like manner two measures were made for the shadow, the width of the box being 2.1 cn. and the distance of the box to the mark

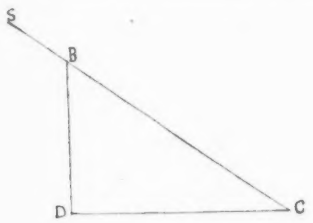


FIGURE 1

fixing the end of the shadow 105.7 cn., making its whole length 107.8 cn. The numbers given are, of course, the mean of several measures.

The method of finding the Sun's noon altitude from this observation is illustrated in Figure 1, where *DC* is the length of the shadow and *BD* the height of the gnomon. As *CS* is the line of direction toward the Sun, *BCD* is its angular elevation above

the horizon, that is its altitude, an angle readily computed; for according to adjustment the triangle *BCD* is right-angled at *D*. To obtain its value without calculation, lay off on rectangular paper the lines *DC* and *DB*, in correct proportion and at right angles to each other, mark the line *BC*, cut out the paper form *BCD*, and placing it carefully on a protractor, read off the angle at *C*. In the example given above the numbers were small enough to take one linear space on the paper used, as a centimetre, the unit of measure, and so the numbers were counted off directly. The angle read from the protractor was 33° 4. By trigonometry its value is 33°.2, 0°.2 less than that given by paper and protractor, a difference, however, not unusually large.

Whatever method is employed in finding the meridian altitude of a heavenly body, the latitude is derived in practically the same manner; but there are slight variations in reduction depending upon the position of the heavenly body in reference to the celestial equator and the north pole. These are illustrated in Figure 2, where

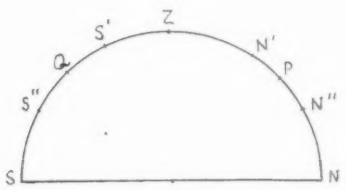


FIGURE 2

1. *NPZQS* represents the celestial meridian,
2. *N* and *S*, the north and south points on the horizon,
3. *P*, the pole, and *N'* and *N''*, celestial objects above and below the pole,
4. *Q*, the point where the celestial equator intersects the meridian,
5. *S'* and *S''*, celestial objects above and below the equator, *QS'* and *QS''* being their declinations, respectively.

When the body is south of the zenith, the problem of deriving latitude from meridian altitude consists in finding the declination of the zenith, *QZ*, for that is equal to the latitude of the place. The simplest case is when the body is on the equator as it crosses the meridian, for then the complement of its altitude *QS* gives *QZ* directly. The required conditions are met with sufficient exactness for naked-eye observers, by the Sun at the equinoxes, two or three stars, and now and then a bright planet. For heavenly bodies not on the equator, it is usually necessary to

know their declination. Thus if the body observed crosses the meridian at S', its zenith distance $S'Z$ must be increased by its declination QS' to give the declination of the zenith QZ. If it is at S'', its zenith distance $S''Z$ must be decreased by the numerical value of its declination QS'' to give the required zenith distance QZ; or if regard is had to the minus sign of south declination, the declination in both cases is added to the body's zenith distance.

On the other hand when the celestial object is north of the zenith, the problem consists in finding the altitude of the pole, PN, for that is equal to the latitude of the place. Suppose the object observed to be above the pole at N', then its altitude NN' must be decreased by $N'P$, the complement of its declination, to obtain PN the altitude of the pole. If the object is below the pole at N'', its altitude $N''N$ must be increased by $N''P$, which equals the complement of its declination.

The point S'' in the figure illustrates the position of the Sun in the observation given above and latitude is found as follows:

Sun's noon altitude from gnomon, by calculation,	33°.2
Sun's zenith distance,	56 .8
Sun's declination November 2, 1905.	−14 .7
Latitude from single gnomon observation,	42 .1
Truel atitude of Northampton,	42 .3
Error of observation,	0 .2

If the Sun's altitude is taken as read from the protractor the error is 0°.4, but this is not unreasonably large. Standards of accuracy must not be too exacting for young, inexperienced students, working with home-made appliances. Under these conditions it has been the writer's general rule to accept determinations of latitude within a degree. Few students except with small classes can be given a second trial on any exercise requiring instrumental aid and personal help from the instructor, and it is hardly fair to reject a result on account of an error larger than the average, when its size is often due to conditions, for example the combining signs of accidental errors, over which the youthful observer has no control.

To illustrate the actual distribution of errors the following record of gnomon observations for latitude is taken from the class of fifty-one students who began the study of astronomy last fall at Smith College:

25 had errors of 0°.2 or less,
12 had errors between 0°.3 and 0°.5,
12 had errors between 0 .5 and 1 .0,
1 had an error over 1 .0, evidently due to a mistake in taking measures.
1 failed to take the observation.

The North Star is the star for determining latitude from altitude. It is never far from the north pole, crosses the meridian twice in twenty-four hours, and at all points of its small diurnal path has an altitude never differing much from that of the pole. These differences are functions of its hour-angle and with that as argument, the required correction for any hour and minute is readily taken from Table IV, given in the last pages of the American Ephemeris.

The observations for finding time are somewhat more exacting than in determining latitude, but the difficulty with this problem lies in the reductions. It is the preparation for this part of the work that taxes the resources and ingenuity of teachers. At first care must be taken to shield students so that they will not come unprepared and too precipitantly upon the difficulties and perplexities of the subject. Much depends upon the method of approach. A large part of what is to be taught naturally groups itself about two questions. What kind of time is kept by our clocks and watches? How can they be compared with heavenly bodies so that we may learn how much they are fast or slow? Some such questions as these may perhaps be thrown out as bait while the rather prosaic task of laying a good foundation goes patiently on.

The first mention of time will inevitably come soon, very likely in the second or third lesson when the common almanac is taken up and the attention is called to the data that it contains. Students will note that many times are given, the hour and minute when the Sun and Moon rise and set, when the Moon changes its phase, when bright stars "south," that is cross the celestial meridian, and of many "aspects" of planets, indicated by quaint symbols. There is also the column headed "Sun fast" which gives a hint that sun time and clock time are not the same. Thus, even a cursory examination of the almanac throws emphasis on the importance of understanding about different kinds of time, and opens the way for fundamental definitions. Later, distributed in different lessons, follow such topics as, standard meridians, time belts, "equation of time, "Sun fast," and methods of changing from one kind of time to another.

There will of course be large differences in the treatment of time by different teachers and by the same teacher with different classes. To illustrate one form and order which for substance of statement has stood many actual tests in the class-room, the writer begs leave to introduce a few paragraphs from the manuscript of a book not yet ready for publication.

"Early in any elementary course in astronomy, it is important to distinguish between apparent, mean and standard time. The Sun in the sky controls apparent, or Sun time. The instant when it crosses the meridian marks apparent noon, and at any moment its hour-angle is apparent time. Since, however, the real Sun does not mark off days exactly of the same length, it is necessary in regulating clocks and watches to make use of a ficititious or mean sun, which moves at a perfectly uniform rate. This mean sun, never far from the real Sun, controls mean time. The instant when it crosses the meridian of a place marks local mean noon, and at any moment its hour-angle, reckoned from the local meridian, is local mean time. This kind of time was long used in practical affairs of life; but some decades since railway travel gave rise to the troublesome question, how far on either side does the time of one meridian extend? A difficulty that was finally settled by establishing standard meridians an hour apart and standard time, now in general use, is thus defined. The mean Sun controls standard as well as local mean time. The instant when it crosses the standard meridian ot a place marks standard noon, and at any moment its hour-angle, reckoned from the standard meridian, is the standard time of the place."

"Standard meridians for reckoning time are in use in all parts of the world, being uniformly designated by the number of degrees they lie west of the Greenwich meridian. The four in our country are 75, 90, 105 and 120 degrees west of Greenwich, each giving its time to the territory lying within about seven and one half degrees of longitude on either side of it. There are then four time belts named as follows:

Eastern Stand. Time	with Stand. Merid.	75°, or 5 h w. of Greenwich
Central " " " " "	90 , "	6 " " " " "
Mountain Time	105 , "	7 " " " "
Pacific Time	120 , "	8 " " " "

When the longitude of any place is known, its local mean time is readily changed to standard time, and *vice versa*. For example, Lawrence, Kansas is in longitude $6^h\ 21^m$ w., and the Sun in its diurnal course to the west, comes first to the standard meridian of the place. 6^h. w., and marks noon there, but not till 21^m later does it reach the local meridian, so standard time at Lawrence, Kansas is 21^m later than local mean time."

"The difference between apparent and local mean time is known as the 'equation of time.' It is constantly changing but so slowly that for most, if not all naked-eye, exercises the noon value for Washington may be used through the day and through-

out the country. "Sun fast" in the small almanacs is as a rule, simply the equation of time copied from the Ephemeris, the signs minus and plus being replaced by "fast," and "slow." Apparent time is changed to mean time by adding or subtracting the equation of time, as by definition that is the difference between the two kinds of time. As an illustration, let it be required to find the local mean time corresponding to apparent time, $3^h\ 11^m\ 54^s$ P. M., March 13, 1907. On page 401 of the Ephemeris for 1907, the equation of time is given as $+9^m\ 49^s$, for apparent noon, the plus sign indicating that the real Sun is slow as compared with the mean Sun. Since the mean Sun is ahead, its time is later and we have,

1907 March 13, $3^h\ 11^m\ 54^s$ p. m., Apparent time
$9\ \ 49$ Equation of time
$3\ \ 21\ \ 43$, p. m., Local mean time."

Any condensed outline like that given above will need to be elaborated and illustrated not a little in class-room treatment. Nothing will be lost by going slowly with the theoretical discussion while observations for time, along with many others, are being carried forward.

Astronomers usually obtain time by observing the stars, and it is quite possible for elementary students to follow their example. There are, however, good reasons why they should get time from the Sun. The degree of accuracy within their reach can be attained as easily by the Sun as by the stars, and any exercise that can be placed in the daytime relieves the pressure in the evening, for most observations must be taken then. By observing the Sun, watch errors can be worked out without complicating the problem with sidereal time. So in the judgment of the writer, the three ways for the beginner to find time are:

1. From the noon shadow of the gnomon post,
2. From the noon transit of the Sun over plumb lines,
3. From sun-dial readings.

For the first of these observations, as in determining latitude, the gnomon shaft must be vertical to the level surface receiving its shadow. A few mimutes before Sun noon the observer begins to watch the moving shadow, and at the instant when its edge coincides with the meridian, "time" is called, and a recorder notes, the second, minute and hour shown by the time-piece used. To aid in getting a distinct shadow and sharp line, a strip of white paper may be fastened over a large part of the meridian line and then this line prolonged across the paper.

In preparing for the Sun's transit, glasses must be carefully

selected. They should be dark enough for one to look directly at the Sun and yet not too dark for the plumb lines to be seen distinctly. No particular method of supporting the two plumb lines is essential, but they must fall freely and the points of the bobs should come to rest exactly over the meridian line. If this line is well determined, the greater the distance between the plumb lines the better. In practice, a space of between two and three feet has proved satisfactory. After adjustments are made, if there is any wind, it is well to steady the bobs by putting them in jars of water. Three times of transit are noted, when the first limb, the center, and the second limb of the Sun, comes in contact with the two plumb lines seen as one. It is not amiss to practice beforehand in holding the head so that the nearer line appears to coincide exactly with the further one.

Any sun-dial requires care in construction. For the horizontal dial the following points are important. The graduations should be as accurate as possible, with the hour spaces divided into five-minute spaces, the axis of the style should be in the same vertical plane as the noon line, intersecting that line at the center of the graduations, and inclined to the dial face by an angle equal to the latitude of the place. Before readings are taken the instrument is placed on the established meridian line, adjusted so that it is level and the noon line is in the plane of the meridian. The reading of the dial consists simply in noting the instant when the shadow of the style is bisected by one of the five-minute lines. Instead, however, of calling "time" once, it is easier for many to note two times, that is the first instant when bisection seems to occur, and again when it has certainly occurred. The two will not differ by many seconds, but the nervous tension is lessened, and the mean of the two readings is more likely to be correct than the single one. This is a device that it is well also to employ with the noon shadow of the gnomon post.

These three observations for time, though made quite differently, are reduced in nearly the same manner, if the same kind of time is used in recording, so only one need be considered in detail. To bring out the different steps more clearly the following actual observation is taken.

"At Northampton, Mass., Saturday, November 18, 1905 the Sun's noon transit over plumb lines was taken, and the mean of the three times recorded gave $11^h\ 34^m\ 41^s$, a. m., Eastern Standard Time, as the watch was regulated to keep that kind of time."

Now the problem is this, having the standard time of apparent noon to find how much the watch was fast or slow according to

the observation. By means of the "equation of time," and the difference between local and standard time, it is possible to obtain a rigorously correct value for the standard time of apparent noon, and then the difference between the observed and computed times gives at once the error required. These two steps are simple, if the fundamental precepts already noted are kept in mind. Thus, the noon of apparent time, like any other hour, is reduced to local mean time by the equation of time. For the given date its value is $-14^m\ 47^s$, the minus sign indicating that the real Sun is ahead, so $12^h\ 00^m\ 00^s - 14^m\ 47^s$ or $11^h\ 45^m\ 13^s$ is the local mean time of Sun noon. This in turn is reduced to standard time by subtracting $9^m\ 27^s$, that being Northampton's longitude east of its standard meridian, and so $11^h\ 45^m\ 13^s - 9^m\ 27^s$ or $11^h\ 35^m\ 46^s$ is the standard time of apparent noon by calculation. Comparison with the observed time, $11^h\ 34^m\ 41^s$, shows that the watch error was $1^m\ 5^s$; and the watch was slow for it should have registered the later time.

By arranging these steps in concise form we have:

Noon of apparent time	12^h	00^m	00^s
Equation of time		14	47
Local mean time of apparent noon	11	45	13
Difference between local and standard time		9	27
Standard time of apparent noon computed	11	35	46
Standard time of apparent noon observed	11	34	41
Watch slow by observation		1	5

The watch compared with the sidereal clock of the Observatory was found to be $1^m\ 6^s$ slow, to the nearest second, making the error of the observation one second. But this small error must not be taken to mean that the observation of the individual student was remarkably good, nor that the method employed will often yield results agreeing so closely with critical determinations of time. Doubtless the accidental errors happened to have opposite signs.

A higher degree of accuracy is possible in finding time than in determining latitude; but doubtless few with experience will question Professor Young's statement that any determination of time within a minute is not bad for inexperienced students, using home-made appliances.

All but two of the class of fifty-one students, mentioned in connection with the gnomon observation for latitude, took the Sun's noon transit over plumb lines with errors distributed as follows:

7 had errors less than 15^s,
21 had errors between 15 and 40^s,
17 had errors between 40 and 60,
4 had errors of one minute or more.

Of this number only eight, and they mainly on account of untoward conditions of wind and weather, were given an opportunity to take a second observation.

Under the head of "time comes the problem of finding the length of the sidereal day. Since it is usual to express its length as so many hours and minutes of the mean solar day, the first step is to have in mind a clear idea of these days. The mean solar day is the one in common use, and is simply the interval of time between noon as indicated by the mean Sun on one day and on that following. But when time-pieces in daily use, are, as almost always, regulated to keep mean solar time, the mean solar day may be defined as the interval elapsing between the hour a watch shows one day, and the same hour the next day, assuming that it neither gains nor loses meanwhile. The sidereal day is the time it takes the Earth to turn once on its axis. It is measured by the stars, for they are so far away that they appear to us as fixed points. If then the Earth in turning on its axis brings a certain star to our meridian, an entire rotation must be made before this star appears again on the meridian. So the interval between the transits measures the length of the sidereal day, statements that hold true for any fixed line of reference as well as the meridian.

These definitions provide a criterion for comparing the length of the sidereal and mean solar day. For example, suppose the times of star transits are recorded by a mean time watch, keeping perfect time; if the star under observation crosses the reference line at precisely the same instant night after night, the two days are equal in length: if the star crosses later and later from night to night, the sidereal day is the longer, but if earlier from night to night, it is shorter than the mean solar day. The following observation is taken to illustrate the numerical work involved.

"The transit of the star Fomalhaut was observed over fixed plumb lines, Monday, October 9, 1905; and a week later, October 16, the transit of the same star was taken over the same lines. The times of transit by a mean time watch were $8^h\ 39^m\ 40^s$ and $8^h\ 12^m\ 10^s$ respectively."

On the first night the watch was found to be 42 seconds slow, the second night 29 seconds slow, giving,

Oct. 9, Fomalhaut's time of transit		$8^h\ 40^m\ 22^s$
16 " " " "		8 12 39
Second transit earlier than first by		27 43

Now if the sidereal and mean solar days were of the same length, the second of these times of transit should be just the same as the first. But as the second does come earlier by about 28^m, the seven sidereal days are shorter than the seven mean solar days by so many minutes, and one sidereal day is shorter by about 4^m, carried to seconds the value is $3^m\ 57^s$; and this differs only one second from that given in Chauvenet's Practical Astranomy.

Here, as the quantity sought is the difference between observations, and the interval seven days, it is possible to obtain a decidedly higher degree of accuracy than in finding directly a single watch error. It is probable then that the error of the student's observation given above is a real test of accuracy and not accidental, a conclusion also supported by the complete record of the class of 26, every member of which took the same observation in the same way, with errors distributed thus:

1	had an error of	0,
12	had an error of	1,
6	had errors between	1 and 5,
7	had errors between	5 and 9.

In such observations as these, where plumb lines are used at night, they may be sufficiently lighted by a good electric flash light held in the hand.

There is little point in students taking observations for time, unless there is some way to determine the errors involved, at least within a few seconds. This degree of accuracy ought to be obtained by a good watch, if it is carefully regulated and its error found from day to day by comparison with time signals so widely distributed from observatories. A note-book record should of course be kept of errors and rates.

If time and taste permit, doubtless many teachers would find it interesting to regulate an inexpensive time-piece to sidereal time, ascertaining its errors by plumb-line transits of stars. Such exercises would certainly give vividness to their instruction.

Lawrence, Kansas.

HALLEY'S COMET.*

F. W. HENKEL, B.A., F.R.A.S.†

The shortly expected return of this well-known object, which was the first of these bodies known to move in closed paths round the Sun, and the remarkable phenomena attending its last appearance (in 1835 and 1836) render Halley's Comet a peculiar object of interest at the present time.

Newton in the third section of the Principia, first showed that a body moving under the influence of a force varying inversely as the square of the distance from the center of force, will describe one or other of the curves known as the "conic sections," *i. e.*, either an ellipse (or circle, as a special case), a parabola, or a hyperbola. These three curves may all be obtained by cutting a cone in different ways by a plane, but perhaps they may be more intelligibly defined to the non-mathematical reader as obtained by throwing the shadow of a circular disk upon a plane, such as the surface of a table. If however, the disk is held parallel to the table, we shall get a circle; if it is held edgeways to the light, the shadow will be a straight line. If now we raise our disk so that its highest point is on a level with the source of light, we shall get a curve known as a parabola, which will be oval at one end, but the two sides will open out. If now we hold our disk still higher, we shall get another curve still, whose two sides will separate even further from one another. This curve is known as the hyperbola.

Whilst the planets move in ellipses, so little differing from circles that if represented on paper the deviation is not perceptible, on the other hand, most comets are found to move in orbits so nearly parabolic that only in a few cases are they known to be otherwise. A great comet which appeared in 1680, and approached very close to the Sun, was the first whose path was calculated as a parabola, though there is some reason to believe that it was not truly so, but an enormously elongated ellipse.

In 1682 a comet was observed by Newton, Halley, and others, and on examining the circumstances of its motion, Edmund Halley computed its orbit on the supposition that it was a parabola. Comparing his results with observations of previous comets, for which purpose it was necessary for him to compute

* *Knowledge and Scientific News*, March, 1907.

† Late Director of Markree Observatory.

their orbits from the necessarily imperfect observations of earlier times, he found that in 1531 and 1607 comets had appeared which followed so nearly the same path as this one that he ventured to assert its identity with them, and to predict its return in a period of about 75 years. It was afterwards ascertained that comets had been seen in 1066, 1378, and 1456 whose paths were the same as that of the comet of 1682, and it is now known that all these were apparitions of one and the same body. In 1066 its appearance was figured on the Bayeux tapestry, and it was regarded (after the event) as an omen of the Norman Conquest. In 1456 the comet is said to have been of extraordinary splendor, its tail sixty degrees long, and it is stated that a papal bull was fulminated against the Turks and the comet, and it was ordained that the bells of all churches should be rung at mid-day. Although Halley had predicted its reappearance, he did not live to observe this himself, dying in 1742, at the age of 83, after having been Astronomer Royal for twenty-three years. He pointed out that the comet must have passed very near the planet Jupiter in the interval between 1607 and 1682, and its velocity increased, thereby resulting in a shortening of its period of revolution. Thus he concluded that, whilst the interval between 1607 and 1682 was only 75 years, the following revolution would probably take a longer time; but the then state of mathematics did not enable him to make the necessary calculations to determine this with accuracy. Were the Sun and comet alone existing in space, the latter's path would be an exact ellipse, and the period of its revolution always the same. This is, however, not the case. Besides the Sun there are also the planets, and these, by the law of gravitation, attract, and are attracted by, one another, and other bodies. Their masses, however, being very small, in comparison with that of the Sun, the general nature of the paths pursued by the planets and comets is not changed by this action; but deviations nevertheless arise, which are the more perceptible as their masses are greater and their approaches more close.

Thus Jupiter, the giant planet of our system, whose mass is about $\frac{1}{1000}$ that of the Sun, has at times a greater effect on comets when near to him than the Sun itself. Lexell's comet of 1770 must have been at one time fifty-eight times less distant from Jupiter than from the Sun, and so the planet's attraction ($\frac{58^2}{1000}$ that of the Sun) must have been three times greater.

The celebrated Clairaut, who so greatly advanced the science of astronomy by his work on the Moon, as well as by his re-

searches in pure mathematics, undertook the great labor of calculating the effect of the action of the planets upon Halley's Comet for a period of about 150 years, and in a memoir presented to the *Academie des Sciences*, at Paris, he predicted the date of perihelion as the eighteenth April, 1759, subject to an uncertainty of about a month. As the result of his calculations he estimated that the period of revolution of the comet was increased by 100 days on account of the action of Saturn, and 518 days by Jupiter. It was first seen by Palitsch, a Saxon peasant, about the end of 1758, and came to perihelion on March 12, 1759, just a month earlier than the time assigned by Clairaut. Before its next return the orbit was calculated by no less than four mathematicians, Damoiseau, Pontécoulant, Rosenberger, and Lehmann, and they all agreed in giving a day in the month of November, 1835, as the time of its perihelion passage. It was first seen at Rome early in August of that year, and was visible up to the sixteenth of November in the Northern Hemisphere.

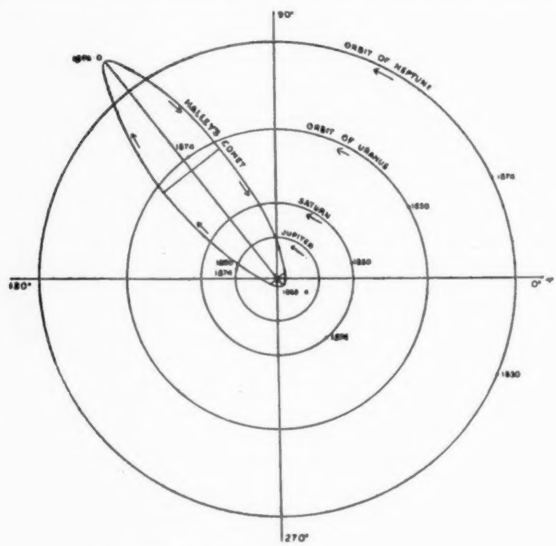
After this, passing its perihelion on that day, it was seen at the Cape and at Melbourne up to the early part of May, 1836, when it finally disappeared from view. Very careful observations and elaborate drawings of its appearance were made by Sir John Herschel, who was then in South Africa. At first it presented the appearance of an almost round nebula, having a bright nucleus not quite at its center. By the beginning of October, 1835, a small tail appeared, and this reached a length of about 20° by the middle of the month. After this the tail diminished, so that before the time of perihelion (November 16) it had again disappeared. On the second of October, the day when the tail was first seen, an emission of light was seen coming from the nucleus, on the side presented towards the Sun. This emission ceased for a time and then re-commenced on the eighth of that month. At this time one observer perceived what he called a "second tail" in a direction opposite to the original tail, thus presented towards the Sun. The shape and brightness of the emanations continually varied from the fifth to the twenty-second of October. At one time two or three emanations were seen to issue in different directions, these having forms sometimes like that of a gas flame coming from a flattened opening, at other times only slightly divergent, and again occasionally only one jet was seen. When more than one such jet or emanation was visible, the principal jet of light oscillated in direction to and fro on either side of the line directed towards the Sun, "like a compass needle thrown into vibration and oscillating about a mean position." Sir J.

Herschel concluded, from his own observations and those of others, that the matter of the nucleus is largely converted into vapor by the Sun's heat, and escapes in jets and streams from the parts turned towards the Sun. This matter is, however, prevented from proceeding in this direction by some force directed from the Sun, much more powerful than gravitation (and repulsive). Being thus repelled from the Sun with considerable velocity, it must leave the nucleus altogether, and consequently, at each approach the comet must lose a portion of its substance, for the feeble attractive power of the nucleus will prevent this matter being retained within the comet's sphere of attraction, and it will be too far away to be re-absorbed afterwards. Thus it is probable that at each apparition the comet will be less conspicuous. After passing its perihelion, the comet was not seen again till near the end of January, when it had no longer a tail, but was seen as a small, round disk, surrounded by a "coma" or nebulous envelope. As the comet gradually receded from the Sun this coma disappeared as though absorbed into the disk, and this latter increased greatly in size, so that during one week (from January 25 to February 1) it increased in volume forty times. This increase of size continued, so that mainly from this cause it became invisible, its illumination becoming fainter and fainter as its size increased. The shape of the disk changed gradually from a nearly circular form to that of a paraboloid. The nucleus meanwhile remained nearly unchanged, but the ray or jet proceeding from it increased in length and brightness, its direction being along the axis of a paraboloid. "If," says Herschel, "the office of the jets was to feed the tail, the office of the ray would seem to have been to conduct back its successively condensing matter to the nucleus."

The comet's envelope and ray gradually faded, and as last seen it had the same form as in the previous August, viz., that of a small, round nebula, with a bright point near the center. In all, it was visible from the fifth of August, 1835, to the fifth of May, 1836, a period of nine months.

The period of revolution of this comet is given in Herschel's "Outlines of Astronomy," as 27,865.74 days, so that, since it passed its perihelion on the fifteenth of November, 1835, it should again return to this position on March 2, 1912; but on account of the considerable disturbing action of the planets Jupiter, Saturn, and Uranus, the actual date may differ considerably from this. So eccentric is the position of the Sun in its orbit, that whilst at perihelion the comet's distance from the Sun is about

0.586 of the Earth's distance, or about fifty-five millions of miles, it recedes to a distance of 35.4 times that of our Earth, or about 3,300 millions of miles considerably greater than that of Neptune. Whilst the planets all move in orbits lying nearly in the same plane, the comet's orbit makes an angle of 17° with the Ecliptic (plane of the Earth's orbit), and its motion therein is in a direction contrary to that of the planets (and of most of the other short period comets), or is retrograde. Whilst the planets move in a direction opposite to the hands of a clock, as seen from our northern latitudes, the comet of Halley moves in the "clockwise" direction (as shown in the accompanying diagram). This comet, as also five others, viz., Pons' Comet, seen in 1812 and 1884; Olbers' Comet, seen in 1815 and 1887; De Vico's Comet of 1846;



Perehelion dist. 0.59
Aphelion dist. 35.4
Longitude of Perihelion 305° (π)
Longitude of ascending node 55° (Ω)

Brorsen's Comet of 1847, and Westphal's Comet of 1852, passes near Neptune's orbit at its aphelion, and these comets are sometimes known as Neptune's family of comets. If at any time a comet enters our system from an infinite distance, moving in a parabola under the Sun's attraction, it will have its motion either accelerated or retarded when it comes near any of the

planets. The smallest increase of velocity will change the parabolic orbit into a hyperbolic one, the smallest decrease will convert it into an ellipse. In the latter case the comet will become a permanent member of our system. This it is possible is what has actually happened, and the converse case of a loss seems also to have occurred. A comet was discovered in 1770 and was shown by Lexell to move in an elliptic orbit, with a short period of about five and one half years. It was, however, never seen again, nor were any former records of its appearance to be found. Lexell, however, showed that in 1767, when at its aphelion, or furthest from the Sun, the comet must have been fifty-eight times nearer to the planet Jupiter than to the Sun, and that then the planet's attraction on it was three times that of the Sun; that in all probability it had been moving in a parabola, which orbit was converted into an ellipse by the planet's action. He further showed that since the aphelion was close to Jupiter's orbit and the comet's period five and one half years, that of Jupiter being eleven years, at the end of two revolutions of the comet and one of the planet, they would again be close together, 500 times less than their distance from the Sun, so that in all probability the comet's orbit would become again parabolic or hyperbolic. Thus he anticipated its eventual disappearance, and, in fact, it was never again seen. Laplace and Leverrier later showed, however, that Lexell's results were liable to considerable uncertainty.

Although, as we have stated, the motion of a comet is greatly affected by the proximity of a planet, the latter, on the other hand, seems quite unaffected.

Thus, the comet of Lexell approached so closely to the planet of Jupiter that, had its mass been in any way considerable, both that planet and its satellite would have had their orbits completely changed, the comet's distance from Jupiter being, when nearest, less than that of the fourth satellite (the furthest of those discovered by Galileo in 1610). Nevertheless, not the smallest measureable derangement was observed, so that the mass of the comet must have been much less than that of any of these satellites. This seems to be a general rule, no perturbations due to a comet having been ever perceived for any planet. Yet the volume of some comets being at times greater than that of the Sun itself the density of the materials composing them must be extremely low. This is also evident from other considerations. Small stars have been distinctly seen through the head of a comet, even through the nucleus, without perceptible diminution of brightness. In the case of one comet, known as Encké's, from

the name of the discoverer there is reason to believe that its period of revolution is diminishing gradually, and that it is slowly getting nearer to the Sun, as though acted upon by some resistance to its motion. This has been supposed to be due to the "luminiferous ether," but since this retardation seems to have become much less of late years than formerly, and so far no other comet seems to have its motion affected in a similar way, there is considerable doubt about this conclusion. By Kepler's third law, the periodic time of a body moving round the Sun is known from its distance from that body. (The squares of the periodic times are as the cubes of the mean distances.) Thus, a resisting medium, by diminishing the comet's velocity, gives the Sun more power to draw it towards itself, and so, lessening its distance, causes its period to become shorter. So unless the comet be dissipated by loss of material, it will some day fall into the Sun.

Many interesting problems are presented to us by these bodies (of which Halley's Comet is one of the most remarkable and interesting). The question as to the existence of a resisting medium, the nature of the repulsive force (supposed by some to be electrical, which is at times much greater than the gravitational attraction), the condition of the matter composing the comas and the tails, and the origin of these bodies, are all matters concerning which we know but little at present. Many recent writers have received Clerk Maxwell's idea of "radiation pressure" with regard to the phenomena of comets' tails. Light being regarded as an electro-magnetic phenomenon, its incidence on an absorbing substance causes a pressure on the latter. The late Professor Fitzgerald suggested this light pressure as the cause of comets' tails, and observed that each different gas would give rise to a separate tail, owing to the different size and density of its molecules. Since only a small part of the radiation falling on gases is absorbed by them, Arrhenius supposes that the matter repelled by the light pressure is not gaseous, but rather consists of fine particles, condensed from the gaseous emanations. In making some further investigations, Schwartzschild arrived at the conclusion that light pressure is sufficient to account for a repulsive force twenty times as great as gravitation on the cometary tails and appendages, but not for a greater amount of force. Since in some cases a repulsive force as much as forty times that of the gravitative attraction has been observed, the light pressure theory is insufficient to account for these. Of other theories as to cometary appendages, we may mention that out-

lined by Mr. Boys, in his presidential address to Section A of the British Association, 1903. He suggests that radio-active substances in the nucleus may be the cause of these phenomena. If the Sun be electrically charged, the rays will be repelled from the nucleus so as to form a tail, and the different kinds of rays given by radio-active substances would give rise to tails of differing curvatures. It has already been stated that though the mean period of Halley's comet is nearly 77 years, yet, on account of planetary perturbations, the actual interval from one return to the following may differ very considerably from this. In 1862, Dr. Angström published a paper in which he deduced a mean period of 76.93 years from a discussion of all the observed perihelion passages, and stated that this period is affected by two large inequalities. Calculating from his empirical (*i.e.*, observational) formulæ, Mr. Crommelin has obtained the date 1913.08 for the next return to perihelion. The late Compte de Pontécoulant, however, in 1864, published the results of his calculations, giving the date of 1910, May, for the next return, a difference of nearly two and two-thirds years from Angström's result. Messrs. Cowell and Crommelin, of Greenwich, are at present engaged in independently computing the perturbations of this comet, following Pontécoulant's method, and the present writer has also done a little in this direction. Some obvious errors in the values given by Pontécoulant for the change of eccentricity have been detected, and the perihelion distance is nearly the same (0.59, the Earth's distance from the Sun being 1.00) as at the last return, whereas Pontécoulant made it considerably greater (0.68). However, they have arrived at the main result, that the time of return given by Pontécoulant (1910, May) is correct within a month, but, it may be a few weeks earlier; consequently Angström's curve is altogether wrong for this return. Thus they consider his two inequalities to have a very doubtful existence, and that it is possible many of the earlier returns have been wrongly identified by Hind, whose results Dr. Angström used.

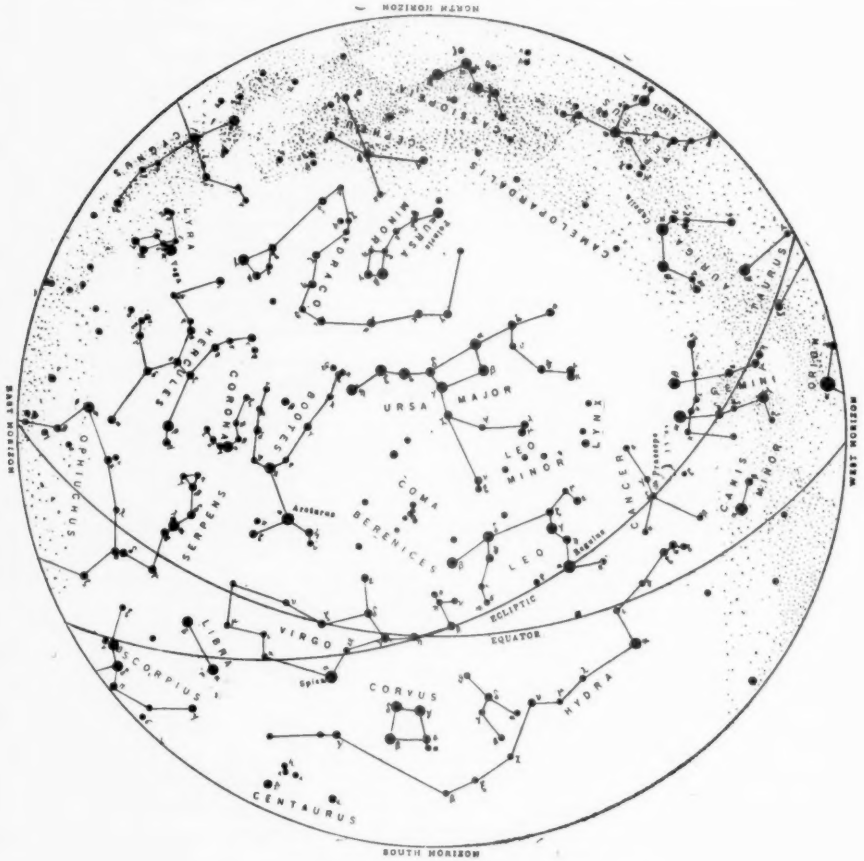
PLANET NOTES FOR MAY, 1907.

H. C. WILSON.

Mercury will be at superior conjunction, i.e., on the farther side of the Sun from us, on May 23, and so will not be in position to be studied during this month. Mercury will be at perihelion on the morning of May 26.

Venus is morning star, and during May will move northeast through Pisces into Aries. The disk of Venus will be gibbous, increasing from 0.80 on May 1 to 0.87 on June 1, while in the same time her brilliance will decrease from 70 to 59.

Mars may be seen best at about four o'clock in the morning in the constellation Sagittarius. The ruddy planet may be easily recognized by its brightness,



THE CONSTELLATIONS AT 9:00 P. M. MAY 1, 1907.

exceeding that of all the stars in the vicinity, and by its color. Its apparent diameter will increase during the month from 13″.5 to 19″. Southern observers will have a splendid opportunity to study the markings of Mars during the next three or four months.

Jupiter may be observed for a short time in the twilight of the evening. His motion is now eastward through Gemini.

Saturn is in Aquarius a few degrees southwest from Venus and so may be seen in the morning. The rings are now very nearly edgewise to us. The Earth passed through the plane of the rings from north to south on April 12.

Uranus will be in conjunction with Mars, the former being 0° 46′ north of the latter, on May 1 at 5 P.M. central standard time. It will therefore be very easy for any observer with a small telescope to find Uranus on the mornings of May 1 or 2.

Neptune will be just one degree due south of Jupiter on May 21 at 6 P.M. central standard time.

Occultations visible at Washington.

Date 1907	Star's Name	Magnitude.	IMMERSION. Washington M.T. h m	Angle f'm N. °	EMERSION. Washington M.T. h m	Angle f'm N °	Duration. h m
May 26	δ Libræ	4.4	9 18	131	10 28	278	1 15
27	B.A.C. 5746	6.2	13 57	94	15 12	285	1 15
29	Piazzi xix 61	5.5	16 58	97	18 05	245	1 07

Phenomena of the Satellites of Jupiter.

1907 Central Standard Time, reckoning from noon.

May	1	6h 44m	II Oc. Dis.	May	15	8h 40m	I Tr. Eg.
	3	6 32	II Sh. Eg.			9 36	I Sh. Eg.
	4	7 23	IV Oc. Dis.		16	6 54	I Ec. Re.
		10 10	IV Oc. Re.			8 15	III Sh. Eg.
	5	6 37	III Oc. Dis.		17	7 22	II Tr. In.
		9 49	III Oc. Re.			9 12	II Tr. In.
	7	7 12	I Oc. Dis.		22	8 22	I Tr. In.
	8	6 40	I Tr. Eg.			9 13	I Sh. In.
		7 42	I Sh. Eg.		23	8 50	I Ec. Re.
		9 29	II Oc. Dis.			8 50	III Tr. Eg.
	10	6 35	II Sh. In.			8 54	III Sh. In.
		7 26	II Tr. Eg.		26	8 50	II Ec. Re.
		9 28	II Sh. Eg.		30	7 44	I Oc. Dis.
	14	9 13	I Oc. Dis.		31	7 11	I Tr. Eg.
	15	7 18	I Sh. In.			7 55	I Sh. Eg.

Note.—In., denotes ingress; Eg., egress; Dis., disappearance; Ec., eclipse; Oc., occultation; Tr., transit of the satellite; Sh., transit of the shadow.

COMET NOTES.

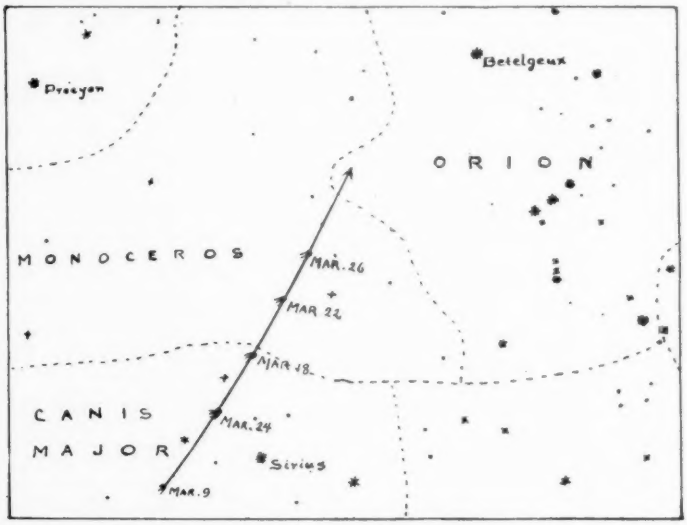
New Comet *a* 1907 Giacobini.—A cablegram from Professor Kreutz. at Kiel, Germany, to Harvard College Observatory announces the discovery of a telescopic comet by Giacobini at Nice, on March 9. On March 12 the comet was pretty faint in our 5-inch telescope, but was conspicuous in the 16-inch, so that

measures of its position were easy. When discovered the comet was in the constellation Canis Major, about 6° east and 1° south of Sirius. It is moving northwestward as shown in the diagram and during April will probably pass along and across the eastern boundary of the constellation Orion.

The following observations are all that are now at hand.

Greenwich M.T.	R. A. h m s	Dec. ° ′ ″	Observer.	Place.
Mar. 9.4040	7 04 31.4	−18 21 17	Giacobini	Nice.
11.5390	6 58 23.0	−16 19 50	Rice	Washington.
12.6995	6 55 22.9	−15 16 24	Gallo	Tacubaya.
12.7006	6 55 16.4	−15 15 26	Wilson	Northfield.
12.7153	6 55 14.2	−15 14 44	Fath	Mt. Hamilton.
14.6771	6 50 04.5	−13 31 30	Moorehouse	Des Moines, Ia.
15.6800	6 44 57.5	−12 34 00	Wilson	Northfield.

Elements and ephemerides as given below have been computed by Messrs. Duncan and Williams of Bloomington, Indiana, Mr. Einarson and Miss Glaney, of Berkeley, Cal., and Miss Lamson of Washington, D. C. In each case the observations used were on dates March 9, 11 and 12.



Apparent Path of Giacobini's New Comet *a* 1907.

Elements of Comet *a* 1907.

Computers	Duncan and Williams	Einarson and Glaney	Miss Lamson
T	Mar. 12.61	Mar. 12.64	Mar. 8.33
ω	313° 24′	313° 19′	311° 11′
Ω	96 25	96 17	95 54
i	142 09	142 14	142 28
q	2.051	2.051	2.048

Ephemeris from the Elements by Duncan and Williams.

Gr. M.T.	R. A. h m s	Dec. °	Brightness
Mar. 14.5	6 50 47	−13 38	0.90
18.5	6 42 03	−10 15	
22.5	6 34 51	− 7 08	
26.5	6 28 57	− 4 19	0.66

EPHEMERIS FROM THE ELEMENTS BY EINARSON AND GLANEY.

Gr. M.T.	R. A. h m s	Dec. ° ′	Brightness
Mar. 14.5	6 50 46	−13 38	0.90
18.5	6 42 01	−10 15	
22.5	6 34 48	− 7 09	
26.5	6 28 54	− 4 20	0.67

EPHEMERIS FROM THE ELEMENTS BY MISS LAMSON.

Gr. M.T.	R. A. h m s	Dec. ° ′	Brightness
Mar. 15.5	6 48 27	−12 46	0.87
19.5	6 40 10	− 9 28	
23.5	6 33 18	− 6 26	
27.5	6 27 44	− 3 42	0.64

VARIABLE STARS.

Minima of Variable Stars of the Algol Type.

[Given to the nearest hour in Greenwich Mean Time beginning with noon. To reduce to Central Standard time subtract 6 hours, or for Eastern time subtract 5 hours.]

U Cephei

	d	h
May	1	7
	3	19
	6	7
	8	19
	11	7
	13	18
	16	6
	18	18
	21	6
	23	18
	26	6
	31	5

Z Persei

May	4	0
	7	1
	10	3
	13	4
	16	6
	19	7
	22	8
	25	10
	28	11

RX Cephei

May	9	2

RS Cephei

May	4	10
	16	20
	29	6

RW Geminorum

May	2	1
	4	22
	7	19
	10	15
	13	12
	16	9
	19	6
	22	3
	24	23
	27	20
	30	17

R Canis Maj.

	d	h
May	2	3
	3	6
	4	10
	5	13
	6	16
	7	20
	8	23
	10	2
	11	5
	12	9
	13	12
	14	15
	15	18
	16	22
	18	1
	19	4
	20	7
	21	11
	22	14
	23	17
	24	21
	26	0
	27	3
	28	7
	29	10
	30	13

Y Camelopard.

May	2	3
	5	10
	8	18
	12	1
	15	8
	18	16
	21	23
	25	6
	28	14
	31	21

RR Puppis

May	7	2
	13	12
	19	23
	26	9

V Puppis

	d	h
May	1	11
	2	22
	4	9
	5	19
	7	6
	8	17
	10	4
	11	15
	13	2
	14	13
	16	0
	17	11
	18	22
	20	9
	21	19
	23	6
	24	17
	26	4
	27	15
	29	2
	30	13

X Carinæ

May	1	9
	2	11
	3	13
	4	15
	5	17
	6	19
	7	21
	8	23
	10	1
	11	3
	12	5
	13	7
	14	9
	15	11
	16	13
	17	15
	18	17
	19	19
	20	21
	21	23

X Carinæ

	d	h
May	23	1
	24	3
	25	5
	26	7
	27	9
	28	11
	29	13
	30	15
	31	17

S Cancri

May	6	23
	16	11
	25	23

S Velorum

May	1	5
	7	3
	13	2
	19	0
	24	22
	30	21

RR Velorum

May	1	9
	3	6
	5	2
	6	23
	8	19
	10	16
	12	12
	14	9
	16	5
	18	2
	19	22
	21	19
	23	16
	25	12
	27	9
	29	5
	31	2

SS Carinae

May	2	18
	6	2

SS Carinae

	d	h
May	9	9
	12	16
	15	23
	19	6
	22	14
	25	21
	29	4

Z Draconis

May	1	18
	3	2
	4	11
	5	19
	7	4
	8	12
	9	21
	11	6
	12	14
	13	23
	15	7
	16	16
	18	1
	19	19
	20	18
	22	2
	23	11
	24	19
	26	4
	27	13
	28	21
	30	6
	31	14

δ Libræ

May	1	6
	3	14
	5	22
	8	6
	10	14
	12	22
	15	6
	17	13
	19	21
	22	5

Minima of Variable Stars of the Algol Type.—Continued.

δ Libræ

	d	h
May	24	13
	26	21
	29	5
	31	13

U Coronae

May	1	8
	4	18
	8	5
	11	16
	15	3
	18	14
	22	1
	25	11
	28	22

R Arae

May	2	2
	6	12
	10	22
	15	8
	19	18
	24	5
	28	15

U Ophiuchi

May	1	4
	2	1
	2	22
	3	17
	4	13
	5	9
	6	5
	7	1
	7	21
	8	17
	9	13
	10	10
	11	6
	12	2
	13	22
	13	18
	14	14
	15	10
	16	7
	17	3
	17	23
	18	19
	19	15
	20	11
	21	7
	22	4
	23	0
	23	20
	24	16
	25	12
	26	8
	27	4
	28	1
	28	21
	29	17
	30	13
	31	9

Z Herculis

	d	h
May	2	0
	3	21
	6	0
	7	21
	9	23
	11	20
	13	23
	25	20
	17	23
	19	20
	21	23
	23	20
	25	23
	27	20
	29	23
	31	20

RS Sagittarii

May	1	6
	3	16
	6	2
	8	12
	10	22
	13	8
	15	18
	18	4
	20	14
	23	0
	25	10
	27	20
	30	6

V Serpentis

May	1	1
	4	12
	7	22
	11	9
	14	20
	18	7
	21	18
	25	5
	28	16

RX Herculis

May	1	17
	2	14
	3	12
	4	9
	5	6
	6	4
	7	1
	7	22
	8	20
	9	17
	10	15
	11	12
	12	19
	13	7
	14	4
	15	1
	15	23
	16	20
	17	17

RX Herculis

	d	h
May	18	15
	19	12
	20	9
	21	7
	22	4
	23	1
	23	23
	24	20
	25	17
	26	15
	27	12
	28	9
	29	7
	30	4
	31	1
	31	23

SX Sagittarii

May	1	3
	5	7
	7	9
	9	11
	11	13
	13	14
	15	16
	17	18
	19	20
	21	22
	23	23
	26	2
	28	3
	30	5

RR Draconis

May	1	16
	4	12
	7	8
	10	3
	12	23
	15	19
	18	15
	21	11
	24	7
	27	3
	29	23

RZ Ophiuchi

May	25	19

RV Lyræ

May	2	20
	6	10
	10	1
	13	15
	17	5
	20	20
	24	10
	28	1
	31	15

U Sagittæ

May	2	9
	5	18
	9	4
	12	13
	15	22

U Sagittæ

	d	h
May	19	7
	22	16
	26	1
	29	10

SY Cygni

May	5	22
	11	22
	17	22
	23	22
	29	22

WW Cygni

May	2	0
	5	8
	8	16
	11	23
	15	7
	18	14
	21	22
	25	6
	28	13
	31	21

SW Cygni

May	4	0
	8	14
	13	3
	17	17
	22	7
	26	21
	31	10

VW Cygni

May	1	12
	9	22
	18	9
	26	19

UW Cygni

May	3	0
	6	11
	9	22
	13	8
	16	19
	20	6
	23	17
	27	4
	30	15

W Delphini

May	2	2
	6	21
	11	16
	16	12
	21	7
	26	2
	30	22

RR Delphini

May	4	14
	9	5
	13	19
	18	9
	23	0
	27	14

RV Capricorni

	h	m
May	4	1
	7	7
	10	13
	12	19
	17	1
	20	7
	23	14
	26	20
	30	2

VV Cygni

May	1	11
	2	22
	4	10
	5	21
	7	8
	8	20
	10	7
	11	19
	13	6
	14	18
	16	5
	17	17
	19	4
	20	15
	22	3
	23	14
	25	2
	26	13
	28	1
	29	12
	31	0

U Z Cygni

May	4	19

RZ Cassiop.

May	1	5
	2	9
	3	14
	4	19
	5	23
	7	4
	8	9
	9	13
	10	18
	11	23
	13	4
	14	8
	15	13
	16	18
	17	22
	19	3
	20	8
	21	12
	22	17
	23	22
	25	2
	26	7
	27	12
	28	16
	29	21
	31	2

Approximate Magnitudes of Variable Stars on March 1, 1907.

[Communicated by the Director of Harvard College Observatory, Cambridge, Mass.]

Name.	R. A. 1900. h	m	Decl. 1900. °	′	Magn.	Name.	R. A. 1900. h	m	Decl. 1900. °	′	Magn
X Androm.	0	10.8	+46	27	14.2*d*	X Monoc.	6	52.4	− 8	56	10.6*d*
T Androm.		17.2	+26	26	11.5 *i*	R Lyncis		53.0	+55	28	11.0*d*
T Cassiop.		17.8	+55	14	10.5*d*	RS Gemin.		55.2	+30	40	11.0 *i*
R Androm.		18.8	+38	1	12.5 *i*	V Can. Min.	7	1.5	+ 9	2	14.6
S Ceti		19.0	− 9	53	10.0 *i*	R Gemin.		1.3	+22	52	13.7*d*
Y Cephei		31.3	+79	48	12.8*d*	R Can. Min.		3.2	+10	11	8.8 *i*
U Cassiop.		40.8	+47	43	14.0*d*	V Gemin.		17.6	+13	17	13.0 *i*
V Androm.		44.6	+35	6	14.0*d*	S Can Min.		27.3	+ 8	32	11.6*d*
RR Androm.		45.9	+33	50	14.0	T Can. Min.		28.4	+11	58	8.6 *i*
W Cassiop.		49.0	+58	1	12.5 *i*	U Can. Min.		35.9	+ 8	37	9.0 *i*
U Androm.	1	9.8	+40	11	12	S Gemin.		37.0	+23	41	13.5*d*
S Piscium		12.4	+ 8	24	10 0*d*	T Gemin.		43.3	+23	59	8.5 *i*
S Cassiop.		12.3	+72	5	11.2*d*	U Puppis		56.1	−12	34	11.5 *i*
U Piscium		17.7	+12	21	13.5*d*	R Cancri	8	11.0	+12	2	11.2*d*
R Piscium		25.5	+ 2	22	14.0	V Cancri		16.0	+17	36	8.5 *i*
RU Androm.		32.8	+38	10	11.5 *i*	U Cancri		30.0	+19	14	11.0 *i*
Y Androm.		33.7	+38	50	14 5*d*	X Urs. Maj.		33.7	+50	30	13.6*d*
X Cassiop.		49.8	+58	46	9.8*d*	S Hydrae		48.4	+ 3	27	12.4*d*
U Persei		53.0	+54	20	8.8 *i*	T Hydrae		50.8	− 8	46	8.6 *i*
R Arietis	2	10.4	+24	35	9.5*d*	T Cancri		51.0	+20	14	9.6 *i*
W Androm.		11.2	+43	50	12.8*d*	W Cancri	9	4.0	+25	39	11.0*d*
Z Cephei		12.8	+81	13	10.0 *i*	Y Draconis		31.1	+78	18	13.5*d*
o Ceti		14.3	− 3	26	4.6*d*	R Leo. Min.		39.6	+34	58	10.5*d*
S Persei		15.7	+58	8	9.5*d*	R Leonis		42.2	+11	54	6.0 *i*
R Ceti		20.9	− 0	38	<13	V Leonis		54.5	+21	44	12.8*d*
U Ceti		28.9	−13	35	12.5*d*	R Urs. Maj.	10	37.6	+69	18	9.6*d*
RR Cephei		29.4	+80	42	<13.5	W Leonis		48.4	+14	15	13.0*d*
R Trianguli		31.0	+33	50	12.0*d*	S Leonis	11	5.7	+ 6	0	10.5*d*
T Arietis		42.8	+17	6	8.5 *i*	R Comae		59.1	+19	20	13.0
W Persei		43.2	+56	34	10.8*d*	R Corvi	12	14.4	−18	42	7.3 *i*
U Arietis	3	5.5	+14	25	10.0*d*	T Can.Ven.		25.2	+32	3	9.5
X Ceti		14.3	− 1	26	8.0 *i*	T Urs. Maj.		31.8	+60	2	10.5 *i*
Y Persei		20.9	+43	50	10.0	R Virginis		33.4	+ 7	32	8.5 *i*
R Persei		23.7	+35	20	8.5 *i*	RS Urs. Maj.		34.4	+59	2	<12
T Tauri	4	16.2	+19	18	12.0	S Urs. Maj.		39.6	+61	38	11.4*d*
R Tauri		22.8	+ 9	56	<13.5	U Virginis		46.0	+ 6	6	8.5 *i*
W Tauri		22.2	+15	49	10.0 *i*	RT Virginis		57.6	+ 5	43	7.5 *i*
S Tauri		23.7	+ 9	44	12.0 *i*	R Hydrae	13	24.2	−22	46	7.0 *i*
T Camelop.		30.4	+65	57	7.8 *i*	T Urs.Min.		32.6	+73	56	7.0 *i*
X Camelop.		32.6	+74	56	14.0*d*	R Can. Ven.		44.6	+40	2	7.2 *i*
V Tauri		46.2	+17	22	8.5 *i*	S Bootis	14	19.5	+54	16	12.8*d*
R Orionis		53.6	+ 7	59	11.5*d*	R Camelop.		25.1	+84	17	13.2*d*
R Leporis		55.0	−14	57	8.5 *i*	R Bootis		32.8	+27	10	11.0 *i*
T Leporis	5	0.6	−22	2	11.0*d*	S Urs.Min.	15	33.4	+78	58	11.0*d*
R Aurigae		9.2	+53	28	12.2*d*	R Coronae		44.4	+28	28	6.0
S Aurigae		20.5	+34	4	8.5 *i*	W Herculis	16	31.7	+37	32	7.7 *i*
W Aurigae		20.1	+36	49	<14	R Draconis		32.4	+66	58	11.5*d*
S Orionis		24.1	− 4	46	14.0*d*	T Draconis	17	54.8	+58	14	11.5
T Orionis		30.9	− 5	32	12.0*d*	T Herculis	18	5.3	+31	0	7.5 *i*
S Camelop.		30.2	+68	45	10.8*d*	W Draconis		5.4	+65	56	13.5*d*
RR Tauri		33.3	+26	19	10.5*d*	X Draconis		6.8	+66	8	10.0 *i*
U Aurigae		35.6	+31	59	<12.5	W Lyrae		11.5	+36	38	9.0
U Orionis		49.9	+20	10	10.8 *i*	RZ Herculis		32.7	+25	58	8.0
V Camelop.		49.4	+74	30	<12	Z Lyrae		56.0	+34	49	8.5*d*
Z Aurigae		53.6	+53	18	9.0 *i*	R Aquilae	19	1.6	+ 8	5	8.5*d*
X Aurigae	6	4.4	+50	15	10.4 *i*	U Draconis		9.9	+67	7	11.0 *i*
V Aurigae		16.5	+47	45	10.0*d*	R Cygni		34.1	+49	58	12.0 *i*
X Gemin.		40.7	+30	23	9.0	RT Cygni		40.8	+48	32	10.6*d*
W Monoc.		47.5	− 7	2	11.4*d*	TU Cygni		43.3	+48	49	12.0*d*

Approximate Magnitudes of Variable Stars on March 1, 1907—Con.

Name.	R. A. 1900. h	m	Decl. 1900. °	′	Magn.	Name.	R.A. 1900. h	m	Decl. 1900. °	′	Magn.
χ Cygni	19	46.7	+32	40	5.5 *i*	RU Cygni	21	37.3	+53	52	9.0*d*
Z Cygni		58.6	+49	46	13.0	RT Pegasi		59.8	+34	38	9.0 *i*
S Cygni	20	3.4	+57	42	10 0 *i*	S Lacertae	22	24.6	+39	48	8.0 *i*
RS Cygni		9.8	+38	28	8.0	R Lacertae		38.8	+41	51	12.0*d*
WX Cygni		14.8	+37	8	8.5	RW Pegasi		59.2	+14	46	13.0*d*
U Cygni		16.5	+47	35	8.0*d*	V Cassiop.	22	7.4	+59	8	9.5*d*
ST Cygni		29.9	+54	38	<13	W Pegasi		14.8	+25	44	9.0*d*
V Cygni		38.1	+47	47	<13	Z Cassiop.		39.7	+56	2	8.6 *i*
RZ Cygni		48.5	+46	59	9.0 *i*	RR Cassiop.		50.7	+53	8	13.5*d*
R Vulpeculae		59.9	+23	26	13.0*d*	R Cassiop.		53.3	+50	50	12.5
X Cephei	21	3.6	+82	40	9.0 *i*	ZPegasi		55.0	+25	21	8.2 *i*
T Cephei		8.2	+68	5	8.0 *i*	Y Cassiop.		58.2	+55	7	8.6 *i*
S Cephei		36.5	+78	10	9.2*d*						

The letter *i* denotes that the light is increasing, the letter *d* that the light is decreasing, the sign <, that the variable is fainter than the appended magnitude.

The magnitudes given have been compiled by Mr. Leon Campbell of the Harvard College Observatory, from observations made at the Vassar College, Whiteside, Swartz and Harvard College Observatories.

Maxima of Variable Stars of Short Period not of the Algol Type.

Unless otherwise indicated the times of maxima only are given; and the times of minima may be found by subtracting the interval printed in parentheses under the names of the stars.

RW Cassiop.

d	h
(−5	19)
May 2	22
17	17

RX Aurigae

(−4	0)
May 3	8
14	23
26	14

Y Aurigæ

(−0	18)
May 1	11
5	7
9	4
13	1
16	21
20	18
24	14
28	11

T Monocerotis

(−7	23)
May 14	7

W Geminorum

(−2	22)
May 3	7
11	5
19	3
27	1

ζ Geminorum

(−5	0)
May 1	12
11	16
21	20
31	23

V Carinæ

d	h
(−2	4)
May 2	3
8	20
15	12
22	5
28	22

T Velorum

(−1	10)
May 3	14
8	6
12	21
17	12
22	4
26	19
31	10

W Carinæ

(−1	0)
May 5	0
9	9
13	18
18	3
22	12
26	21
31	5

S Muscæ

(−3	11)
May 8	4
17	20
27	12

T Crucis

(−2	2)
May 5	9
11	18

T Crucis

d	h
May 18	11
25	5
31	22

R Crucis

(−1	10)
May 5	0
10	20
16	15
22	11
28	7

S Crucis

(−1	12)
May 4	4
8	20
13	13
18	5
22	22
27	15

W Virginis

(−8	5)
May 3	14
20	20

V Centauri

(1−	11)
May 5	2
10	13
16	1
21	13
27	1

R Triang. Austr.

d	h
(−1	0)
May 3	8
6	17
10	2
13	12
16	21
20	6
23	15
27	1
30	11

S Triang. Austr.

(−2	2)
May 2	2
8	10
14	17
21	1
27	9

S Normæ

(−4	10)
May 5	15
15	9
25	3

RV Scorpii

(−1	10)
May 1	11
7	13
13	14
19	16
25	17
31	18

RV Ophiuchi Minimum

d	h
May 3	20
7	13
11	5
14	22
18	14
22	7
25	23
29	16

X Sagittae

(−2	22)
May 2	10
9	11
16	11
23	11
30	12

Y Ophiuchi

(−6	5)
May 3	18
20	21

W Sagittarii

(−3	0)
May 8	12
16	2
23	16
31	7

Y Sagittarii

(−2	2)
May 7	7
14	22
22	12
30	2

Maxima of Variable Stars of the Short Period not of Algol Type.
Continued.

U Sagittarii

	d	h
	(−2	23)
May	4	11
	11	5
	17	23
	24	17
	31	11

β Lyrae

	(−3	7)
	(−3	2)
May	3	14
	9	20
	16	12
	22	18
	29	10

κ Pavonis

	(−4	7)
May	6	9
	15	11
	24	13

U Aquilae

	(−2	4)
May	3	21
	10	22
	17	22
	24	23
	31	23

XZ Cygni
Period 11h.2

May	1	4
	2	3
	3	1
	4	0
	4	22
	5	20
	6	19
	7	17
	8	16
	9	14
	10	12
	11	11
	12	9
	13	8
	14	6

XZ Cygni

	d	h
May	15	4
	16	3
	17	1
	18	0
	18	22
	19	20
	20	19
	21	17
	22	16
	23	14
	24	12
	25	11
	26	9
	27	7
	28	6
	29	4
	30	3
	31	1

U Vulpeculae

	(−2	3)
May	7	12
	15	12
	23	12
	31	11

SU Cygni

	(−1	8)
May	2	16
	6	12
	10	9
	14	5
	18	1
	21	22
	25	18
	29	14

η Aquilae

	(−2	6)
May	1	18
	8	23
	16	3
	23	7
	30	11

S Sagittae

	d	h
	(−3	10)
May	5	23
	14	8
	22	17
	31	3

X Cygni

	(−6	19)
May	15	20
June	1	5

T Vulpeculae

	(−1	10)
May	4	8
	8	19
	13	5
	17	16
	22	2
	22	12

TX Cygni

May	9	14
	24	8

WZ Cygni
Period 14h.
Minimum

May	1	13
	2	17
	3	21
	5	2
	6	6
	7	10
	8	14
	9	18
	10	22
	12	2
	13	6
	14	10
	15	14
	16	18
	17	22
	19	2
	20	6
	21	10
	22	14

WZ Cygni

	d	h
May	23	18
	24	22
	26	2
	27	7
	28	11
	29	15
	30	19
	31	23

RV Capricorni
Period 10h.7

May	1	9
	2	6
	3	4
	4	1
	4	23
	5	20
	6	18
	7	15
	8	13
	9	10
	10	8
	11	5
	12	3
	13	0
	13	22
	14	19
	15	17
	16	14
	17	12
	18	9
	19	7
	20	4
	21	2
	21	23
	22	21
	23	18
	24	16
	25	13
	26	11
	27	8
	28	5
	29	3

RV Capricorni

	d	h
May	30	0
	30	22
	31	19

VY Cygni

	(−2	2)
May	.	17
	10	14
	18	10
	26	7

VZ Cygni

	(−2	12)
	(−3	6)
May	6	2
	11	2
	15	19
	20	19
	25	13
	30	13

δ Cephei

	(−1	10)
May	5	3
	10	11
	15	20
	21	5
	26	14
	31	23

V Lacertæ

	(−1	17)
May	2	8
	7	7
	12	7
	17	7
	22	6
	27	5

88.1906 Lacertæ
Minimum

May	5	3
	10	13
	16	0
	21	11
	26	21

Variable Star 120.1906.—In *A. N.* 4156 Mr. M. Luizet gives the following elements of this variable from five minima observed by Ceraski, Luizet and Nijland.

Minima = J.D. 2417434.33 (Paris m.t.) +6d.862.

Mr. Luizet gives also the following list of comparison stars and light scale:

	BD.			Light Scale.	Mag. m
	°				
h	+47		709	18.5	7.7
g	+47		681	16.2	8.1
f	+47		698	13.5	8.4
a	+47		695	6.5	9.1
b	+47		693	0.0	9.1

The variable ranges from about 8m.2 at maximum to 9m.6 at minimum.

New Algol-Type Variable 193.1906 Cygni.—In *A. N.* 4153 Mr. A. Stanley Williams announces a new variable of the Algol type with a period of fifteen hours. The star is of normal magnitude 10.4 but descends to 11.4 at minimum. Its position is

Epoch	R. A. h m s	Decl. ° ′
1855.0	20 19 14.0	+46 27.1
1900.0	20 20 40.3	+46 35.7

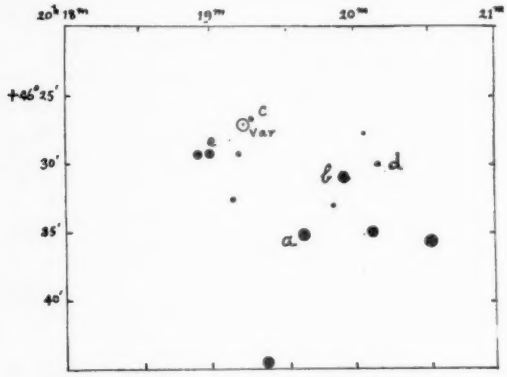


FIGURE 1, CHART OF 193.1906 CYGNI.

From fourteen minima determined from photographs taken, one December 31, 1899, one October 21, 1900 and twelve during the period August 16 to October 14, 1906, Mr. Williams finds the following elements;

Minimum = 1899 Dec. 31 $8^h\ 54^m.2$ (Gr. m. t.) + $0^d\ 15^h\ 05^m\ 12^s.2$ E
= J. D. 2415020.371 + $0^d.6286135$ E.

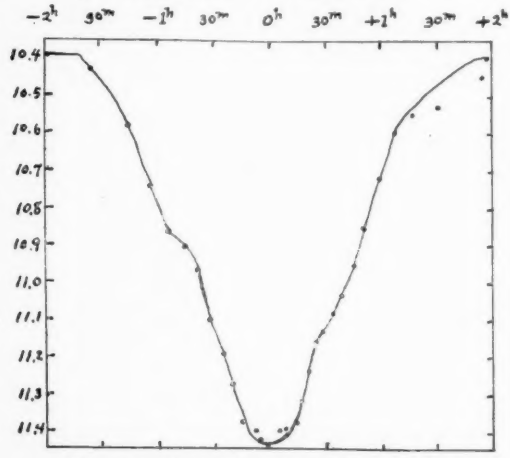


FIGURE 2, LIGHT CURVE OF 193.1906 CYGNI.

The accompanying diagram Figure 1 shows the position of the variable with reference to neighboring stars and the letters designate the comparison stars employed by Mr. Williams. The positions and brightness of the comparison stars are given in the following table:

COMPARISON STARS.

	R. A. 1855 h	m	s	Decl. 1855 °	′	Scale.	Mag.
a	20	19	39.5	+46	35.2	40.2	9.50
e	20	18	59.3	+46	28.9	23.3	10.35
b	20	19	54.5	+46	30.9	20.2	10.50
d	20	20	10.7	+46	30.0	2.7	11.37
c	20	19	17.4	+46	26.5	0.0	11.51

The diagram Figure 2 gives the light-curve at minimum, as determined by Mr. Williams from 145 visual observations. He expresses some doubt as to the reality of the inequalities shown in the curve as drawn.

New Variable 194.1906 Cassiopeiæ.—This was discovered on the night of September 26, 1906 by Dr. R. G. Aitken in the course of his survey for new double stars, and he calls attention to it in No. 111 of the Publications of the Astronomical Society of the Pacific. The star is BD. +51°3676 given as $7^m.8$ in the BD. Its position for 1900 is

R.A. $23^h\ 34^m\ 11^s.55$, Decl. +51° 42′ 31″.3.

Mr. J. D. Maddrill observed the star on nine nights, from September 28 to November 27, 1906 and found it to be diminishing slowly from $9^m.1$ on the first night to $9^m.6$ on the last.

Two New Variables.—In *A. N.* 4157 Professor W. Ceraski calls attention to two new variable stars discovered by Mme. L. Ceraski upon the Moscow photographs. Their positions are as follows:

	R. A. 1900 h	m	s	Decl. 1990 °	′	″
1.1907 Andromedæ	23	59	14	+39	33.1	
2.1907 Camelopardalis	7	10	54.17	+69	51	11

The first star was of the twelfth magnitude upon three photographs taken in August and September 1904, was invisible upon four taken in September 1906, but was of magnitude 9.5 and 9 on the dates December 5 and 9, 1906. The second star is BD. + 69°417, recorded as $8^m.5$. According to twenty-two photographs taken in the interval 1899 to 1906 its brightness varies from $8^m.5$ to $9^m.8$, but the data are insufficient to determine the period.

Laws Observatory Bulletin No. 10.—This Bulletin contains announcement of preliminary results for thirty-two variable stars which are being studied systematically at the Laws Observatory by the aid of a grant from the Gould Fund. Approximate elements are given as follows:

64.1905 Cassiop.	Max. = J.D.	2417082	+ 141^d E
RW Cassiop. (46.1905)	Max. =	2417062.5	+ 14.82 E
RV Androm. (17.1904)	Max. =	2416934	+ 169 E
RV Persei (61.1905)	Max. =	2417624	+ 36 E
RV Tauri (45.1905)	Max. =	2417545	+ 40 E
RY Ophiuchi (77.1905)	Max. =	2417042	+ 154.5 E
RS Draconis (39.1905)	Max. =	2417450	+ 270 E
X Lyræ	Min. =	2417420	+ 50 E
U Vulpeculæ	Max. =	2414204.80	+ 7.98919 E
X Vulpeculæ (161.1904)	Max. =	2417040.85	+ 6.317 E
W Vulpeculæ (5.1904)	Max. =	2417017	+ 249 E
RR Delphini (79.1906)	Min. =	2417424.53	+ 4.601 E
VX Cygni (58.1903)	Max. =	2414934.97	+ 20.125 E
TX Cygni (22.1900)	Max. =	2417010.5	+ 14.71 E
VY Cygni (61.1903)	Max. =	2416370.88	+ 7.857 E
YY Cygni (94.1901)	Max. =	2416638	+ 378 E
VZ Cygni (7.1904)	Max. =	2417062.00	+ 4.864 E
70.1905 Pegasi	Min. =	2417400	+ 175 E
88.1906 Lacertæ	Min. =	2417412.8	+ 5.44 E
SS Androm. (167.1904)	Min. =	2416280	+ 165.8 E
RS Cassiop. (108.1904)	Min. =	2417412.50	+ 6.298 E

GENERAL NOTES.

Mr. Elliott Smith, (Univ. of Minn. '03) Assistant at the Lick Observatory 1903-5, Lick Fellow 1905-6, has been appointed assistant in the Cincinnati Observatory. He was Professor Tucker's assistant with the Meridian Circle at Lick Observatory and has been placed in charge of the Meridian Circle at Cincinnati.

Mt. Hamilton Weather. In the last number (112) of the Publications of the Astronomical Society of the Pacific, Director W. W. Campbell gives the following note: "The Lick Observatory is now passing through the most severe snow blockade that it has experienced at least since 1889-90. Between January twelfth and sixteenth the snowfall exceeded fifty inches. The latter part of the fall was attended by considerable wind, and long stretches of the road were drifted full. The snowfall was remarkable for the low altitude to which it descended. At Smith Creek it amounted to eighteen inches, and the fall extended down to within one hundred or two hundred feet of the level of Santa Clara Valley. No stage has reached the summit since January 12, and at the date of writing, January 22, we are not expecting the stage to come to the summit for another week at least. The wires which gave us telephone connection with the outside world were broken down under the great weight of snow and ice which collected on them. On two days we did not attempt to communicate with the stage, which ascended as far as Smith Creek. On other days the mail and supplies were carried up over the snow by members of the staff. Fortunately, no illness developed, and the inconvenience of the blockade has thus far not been serious. The winter has been unusually cold, stormy, and cloudy. The precipitation to date corresponds to about twenty-one inches of rainfall."

Aurora Borealis. I witnessed tonight one of the best displays of Aurora Borealis for years, I noticed in particular one beam of light pass directly over Aldebaran and a few degrees beyond, to the south. Altogether it was a very pretty display, and was enjoyed by everyone on the streets during the evening.

CURTIS H. THOMAS.

February 9, 1907.
Traer, Iowa.

The Aurora Borealis. Albert R.J.F. Hassard, B. C. L., Toronto, Canada writes under date of January 11, 1907, that on the evening of that day, between ten and eleven, he observed a brilliant display of the Aurora. The night was very clear with a temperature of about fifteen degrees below zero. When he observed the Aurora, Mr Hassard was about eleven miles north of the city of Toronto, Canada, and the active part of the display, as he describes it, was principally from the northern and northeastern horizon. He noticed the effect of the electric lights in Toronto as he looked to the south, that there was some similarity, and some differences between the two. The illumination and the pointed streamers from the city lights were steady and quite constant, while the display in the other parts of the sky made by the Aurora was in a state of change continually. Mr. Hassard speaks of the dark band along the horizon, out of which the streamers seemed to come, and he indicates that this part of the view is that which is commonly seen in a moderately active electrical storm. This storm of which he speaks must have been very general, for the same display was seen in this vicinity. And singularly enough for the first time we ever noticed it the electric lights in the city of Northfield, behaved in a manner altogether similar to what he describes for those of Toronto.

These interesting observations are in full accord with the views of some meteorologists who explain the phenomena of the Aurora as due to the presence of electrical storms. It is also an interesting fact that the activity of the Sun's surface was considerable during the periods of these so-called electrical storms. The solar disturbance was shown by a line of spots reaching nearly across the Sun's disk, a very unusual condition, even one that might produce its effects in the terrestrial atmosphere that would last for several days. That fact was noticed in several places.

There were some things in these Auroræ as related to the condition of the

solar surface that seem to support Dr. Veeder's views published in this magazine some years ago. It was also suggested to us while viewing these interesting displays in the north and northeastern evening sky, to think of the cause of the streamers of light and the pinkish color sometimes seen at the base of some of them. The beautiful experiments which Professor Michaelson of the University of Chicago showed us some years ago in his physical laboratory, were also remembered. Probably we will never forget the surprising effect of an experiment with a novel piece of magnetic apparatus, in which the interference of magnetic waves in a dark magnetic field was so manipulated as to produce light that was easily discernible.

Long steps are now being taken by the physicist in finding out how to transform the various cosmic energies that are within the reach of the human intellect.

The Journal of the Astronomical Society of Canada. The above is the title of a new astronomical bi-monthly whose first number is before us. It presents a very creditable appearance, both in respect to matter and typographical dress. It is edited by C. A. Chant, University of Toronto. He is assisted by W. F. King chief astronomer of the new Observatory at Ottawa, R. F. Stupart, director of the meteorological service of Canada, at Toronto and J. S. Plaskett of the Dominion Observatory at Ottawa, as associate editors.

As the name implies this new publication is to be the organ of the Royal Astronomical Society of Canada.

As outlined in the brief introduction by editor Chant who is president of the Society, *The Journal* will probably replace the annual volumes of the transactions of the Society which have been regularly published for some years past. The attention that the Society gives to amateur workers is most gratifying and certainly very helpful. In this first number the editor puts it well when he says:

"There are a few technical articles on Astronomy, which, if clearly written, have not a real value to the amateur, while the work of the latter is always of interest to his professional brother. If all unite the result will be highly creditable to Canadian Science."

This initial number contains the address of the president of the Society, C. A. Chant, on the progress of astronomy and astrophysics during the year 1906; an account of the meetings of the Society for the year, Astronomy as a Science by W. F. King; Magnetic Disturbance and the Aurora by R. F. Stupart and an article on *o* Ceti by J. S. Plaskett besides a number of other brief papers which make up a valuable table of contents. We wish this new publication abundant success.

Proposed New Astronomical Observatory at Bologne, Italy. Professor Michele Rajna, Director of the Observatory of the University of Bologne, has favored us with a pamphlet copy of his address, reciting the past history of his institution, and recommending the building of a new modern Observatory; also a copy of the newspaper "Carlino" for February 3-4 1907, showing the progress already made with the new enterprise.

The old Observatory, founded in 1712, has had a rather uneventful existence, being in a state of disuse and dilapidation for long periods at a time. An illustration in his pamphlet shows the Observatory to consist of a very tall square masonry tower. An Ertel 3½-inch Meridian circle and a small equatorial are mounted 125 feet above ground on ledges somewhat below the top of the tower. Many past writers are quoted showing the unsuitableness of such a location for telescopic work. The only discoveries noticed in connection with Bologne Observatory in the past are the three comets found by Respighi in 1862-3.

In 1903 Professor Rajna was chosen director and he immediately began to consider the need of a new Observatory in a suitable location. His plans were approved by the faculty and rector of the University. Copies of his address were printed and widely distributed. The Bologne city council heartily indorsed the plan and the necessary legal steps were taken to provide funds. A law passed in 1899 allowing the city to levy a large annual tax in support of its University is thought to give legal status to the enterprise. The tax estimates for 1907 provide for the raising of a fund of 1,306,000 Lira (about $250,000) payable in five yearly installments from 1907 to 1911. Besides this, the council has made possible the procuring of a fine suburban site for the observatory. This is on the hill called Observanza, the property known as the villa Aldini, built in 1811-16 by Count Antonio Aldini, while prime minister of Italy. The house is a large

structure about 165 feet front and 60 feet deep, of classic style of architecture. This building, when remodeled and fitted with modern conveniences, is expected to serve for observatory offices, study and shop, as well as residence for the director and some assistants. Separate buildings will be erected for the various instruments old and new. The principal new instrument proposed is a 12-inch visual refractor. A commission of Italian astronomers has been selected to aid in securing the government approval of the project. The astronomers named are Celoria, Lorenzoni, Millosevich, and Riccò. Everything depends now on the final approval of the Italian Government, which has seemed not unfavorable to the plan thus far.

Erratum: On frontispiece of the March number read W. F. King, chief astronomer and director instead of "Otto Klotz, chief astronomer." Mr. Klotz's position is that of assistant astronomer.

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